Physical fitness among older manual workers

Norheim, Kristoffer Larsen

PHYSICAL FITNESS AMONG OLDER MANUAL WORKERS

BY
KRISTOFFER LARSEN NORHEIM

DISSERTATION SUBMITTED 2020

AALBORG UNIVERSITY
DENMARK

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PHD THESIS

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Dissertation submitted

Dissertation submitted:	March 2020
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ISSN (online): 2246-1302
ISBN (online): 978-87-7210-613-7

Published by:
Aalborg University Press
Langagervej 2
DK – 9220 Aalborg Ø
Phone: +45 99407140
aauf@forlag.aau.dk
forlag.aau.dk

Printed in Denmark by Rosendahls, 2020

CV

Kristoffer Larsen Norheim (KLN) received his Bachelor degree in sport science in 2014 from the Norwegian School of Sport Science, Norway, which included an exchange semester at Montana State University, USA, and summer school at University of Jyväskylä, Finland. He received his Master degree in human physiology in 2016 from University of Copenhagen, Denmark.

With a grant from the Danish Working Environment Research Fund, KLN was enrolled as a PhD-student at the doctoral school of the Faculty of Medicine at Aalborg University. The PhD-project is a collaboration between Aalborg University and Aalborg University Hospital under the supervision of Professor Pascal Madeleine and co-supervision of Associate Professor Afshin Samani, Associate Professor Jakob Hjort Bønløkke, and Professor Emeritus Øyvind Omland.

During his PhD, KLN has given oral presentations at the 6th annual Ramazzini seminar (Ramazzini seminar, 2017, Sønderborg, Denmark), the 20th International Ergonomics Association Conference (IEA, 2018, Florence, Italy) and 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders (PREMUS, 2019, Bologna, Italy). Additionally, KLN has presented posters at the 9th annual meeting of the Danish Society of Biomechanics (DBS, 2017, Aarhus, Denmark) and the 24th annual Congress of the European College of Sport Science (ECSS, 2019, Prague, Czech Republic). He is also a reviewer for Experimental Gerontology and Sports Medicine.

ENGLISH SUMMARY

Life expectancy has increased over the last decades. To accommodate the growing population of older adults, retirement age is currently being raised in many countries. Because aging is associated with a decline in physical fitness, this may be problematic for workers in physically demanding occupations. Although regular physical activity is an important component in slowing the aging process, controversy exists regarding the influence of manual work on physical fitness. Especially for older adults, very little knowledge exists regarding the influence of age and manual work on physical fitness. Delineating age-related changes in physical fitness among older manual workers could point toward physical deficiencies that should be targeted for future interventions. This could provide a better work ability and secure a meaningful retirement for all workers.

The overall aim of this thesis was to investigate physical fitness among manual workers in their last two decades of working life. Further, it aimed to investigate the effects of musculoskeletal complaints on motor control tasks and fatigue development. To accomplish this, a series of five studies were conducted. Study I described the protocol for the experimental assessments that constituted the four latter cross-sectional studies. In Study II it was demonstrated that age and the stage of musculoskeletal pain (acute vs. chronic) differentially affects the structure of handgrip force variability in manual workers. Similarly, Study III showed an age-dependency on the effects of musculoskeletal pain on lower extremity function and dynamic balance. In Study IV, the response times during a hammering task were markedly slower for older manual workers compared with younger controls. Surprisingly, this was not accompanied by differences in hammering accuracy. Lastly, results from Study V indicated that all domains of physical fitness deteriorates with aging in manual workers. Greater handgrip strength and body size, but poorer cardiorespiratory fitness and pulmonary function was found compared with general populations.

In summary, the present thesis indicated that manual workers do not improve their physical fitness by being in jobs in which they are physically active every day. Especially cardiorespiratory fitness, pulmonary function, and motor control seemed to be negatively affected, whereas handgrip strength may be maintained to some extent in these older workers. Of note, physical fitness was more strongly associated with physical work ability after age 60, suggesting physical fitness as a limiting factor only among the oldest workers. Future studies are encouraged to investigate the effects of interventions aiming at increasing cardiorespiratory fitness and reducing fat mass among older manual workers.

DANSK RESUMÉ

Levealderen er steget i løbet af de sidste årtier. For at imødekomme den voksende befolkningsandel af ældre mennesker, hæves pensionsalderen i mange lande. Da aldring er forbundet med et fald i fysisk kapacitet, kan dette være problematisk for arbejdstagere i fysisk krævende erhverv. Selvom regelmæssig fysisk aktivitet er en vigtig komponent i at bremse aldringsprocessen, eksisterer der uenighed om påvirkningen af manuelt arbejde på fysisk kapacitet. Især for ældre voksne findes der meget lidt viden om påvirkning af alder og manuelt arbejde på fysisk kapacitet. En beskrivelse af aldersrelaterede ændringer i fysisk kapacitet blandt ældre håndværkere kan pege på mangler, der bør målrettes mod i fremtidige interventioner. Dette kan give en bedre arbejdsevne og sikre en meningsfuld pensionisttilværelse for alle arbejdstagere.

Det overordnede mål med denne afhandling var, at undersøge fysisk kapacitet hos håndværkere i deres sidste to årtier af arbejdslivet. Endvidere havde den til formål, at undersøge virkningerne af muskel-skeletbesvær på motoriske kontrolopgaver og træthedsudvikling. Til dette blev der udført en serie af fem studier. Studie I beskrev protokollen til de eksperimentelle målinger, der udgjorde de fire følgende tværsnitsundersøgelser. I Studie II blev det påvist, at alder og stadiet af muskel-skeletbesvær (akut vs. kronisk) differentielt påvirker strukturen i håndgrebskraftvariabilitet hos håndværkere. Tilsvarende viste Studie III, at virkningerne af muskel-skeletbesvær på underekstremitetsfunktion og dynamisk balance var aldersafhængige. I Studie IV var responstiderne under en hammeropgave markant langsommere for ældre håndværkere, sammenlignet med unge kontroller. Overraskende var dette ikke ledsaget af forskelle i hammerpræcision. Endelig indikerede resultater fra Studie V, at alle områder af fysisk form forværres med aldring hos håndværkere. Større håndgrebsstyrke og kropsstørrelse, men dårligere kredsløbskondition og lungefunktion blev fundet sammenlignet med generelle populationer.

For at opsummere, så indikerede denne afhandling, at håndværkere ikke forbedrer deres fysiske kapacitet ved, at være i fysisk krævende erhverv. Især kredsløbskondition, lungefunktion og motorisk kontrol syntes at være negativt påvirket, hvorimod håndgrebsstyrken i nogen grad kan opretholdes hos disse ældre arbejdstagere. Det bemærkes, at fysisk kapacitet var stærkere forbundet med fysisk arbejdsevne efter 60-årsalderen, hvilket tyder på, at fysisk kapacitet kun er en begrænsende faktor blandt de ældste arbejdstagere. Fremtidige undersøgelser opfordres til, at undersøge virkningerne af interventioner, der sigter mod at øge kredsløbskondition og reducere fedtmassen hos ældre håndværkere.

ACKNOWLEDGEMENTS

The present thesis could not have been completed without the generous financial support of The Danish Working Environment Research Fund, the recruitment help of the United Federation of Danish Workers, and the people who volunteered to participate in the experiments. I would also like to thank the Otto Mønsted foundation for travel grants enabling participation in scientific conferences.

First and foremost, I would like to thank my main supervisor Pascal Madeleine for the enormous effort you have put into helping me not only with my PhD, but also with my future plans and aspirations. Thanks also to my co-supervisors Afshin Samani–for your attention to detail and for keeping me sharp; Jakob Hjort Bønløkke–for your guidance in the field of occupational and environmental medicine; and Øyvind Omland–for sharing your wisdom and for believing in me as a researcher. Thanks also to the rest of the ALFA-group for scientific sparring throughout the PhD project.

Thanks to my colleagues at Sport Sciences for creating a positive and motivating work environment. Special thanks goes to Ramtin, Silvia, and Rasmus for being excellent office mates and friends.

Thanks to my mom and dad for enduring long phone calls made in frustration and for all your support throughout these three years. Lastly, I would like to thank my girlfriend Lea for all your support and for being a source of inspiration.

- Kristoffer

March 2020, Aalborg

LIST OF STUDIES

This thesis is based on the following articles hereafter referred to by their Roman numeral in the text. The included studies are provided in the appendices section.

STUDY I

Norheim KL, Hjort Bønløkke J, Samani A, Omland Ø, Madeleine P. The Effect of Aging on Physical Performance Among Elderly Manual Workers: Protocol of a Cross-Sectional Study. *JMIR Res Protoc*. 2017

STUDY II

Norheim KL, Samani A, Bønløkke JH, Omland Ø, Madeleine P. The effects of age and musculoskeletal pain on force variability among manual workers. *Hum Mov Sci*. 2019

STUDY III

Norheim KL, Samani A, Bønløkke JH, Omland Ø, Madeleine P. On the role of ageing and musculoskeletal pain on dynamic balance in manual workers. *J Electromyogr Kinesiol.* 2020

STUDY IV

Norheim KL, Samani A, Madeleine P. Whack-a-mole and the effects of age on response time, accuracy and shoulder/arm kinematic. *Submitted.*

STUDY V

Norheim KL, Samani A, Bønløkke JH, Omland Ø, Madeleine P. Physical performances show conflicting associations in aged manual workers. *Sci Rep.* 2020

ABBREVIATIONS

ALFA	Aldring og fysisk arbejde (Aging and physical work)
BIA	Bioelectrical impedance analysis
BMI	Body mass index
COPD	Chronic obstructive pulmonary disease
CRP	C-reactive protein
FEV_1	Forced expiratory volume after 1 second
FFM	Fat-free mass
FVC	Forced vital capacity
HGS	Handgrip strength
HR	Heart rate
IL-6	Interleukin-6
LyE	Lyapunov Exponent
MVC	Maximal voluntary contraction
RFD	Rate of force development
RPE	Rating of perceived exertion
SaEn	Sample entropy
STS	Sit-to-stand
$\dot{V}O_2max$	Maximal rate of oxygen uptake

PREFACE

The present thesis concerns physical fitness among older manual workers. Because there may be several ways to interpret and define *older*, *manual workers*, and *physical fitness*, following is a list of how these terms are defined within the context of the present thesis. It is acknowledged that other definitions exists.

Age may be defined as the time since a person was born (chronological age), measured or self-perceived health (functional/biological age), social or self-perceptions about one's age (psychosocial age), job tenure (organizational age), and home situation (life-span age) (1). In the present thesis, age refers to chronological age and older workers are considered as those aged ≥ 50 years.

Manual workers may be defined as people who are working in an occupation that requires physical work done by humans. Related terms include blue-collar workers, physical workers, and laborers. In the present thesis, manual workers refer to people who are actively working in or who are retired from a skilled occupation that requires physical activity such as carpenters, bricklayers, and plumbers.

Physical fitness may be defined as a set of health and skill-related attributes (2). Although physical fitness was not defined and operationalized in the individual studies of this thesis, it is included herein as the overarching concept describing all studied outcomes, relating not only to performance but also to health. Related but not equivalent terms include physical performance and physical capacity. In the present thesis, physical fitness refers to attributes that relate to the ability to work and perform physical activities and be in good health. The operationalization and measured items are shown in **Figure 0-1**.

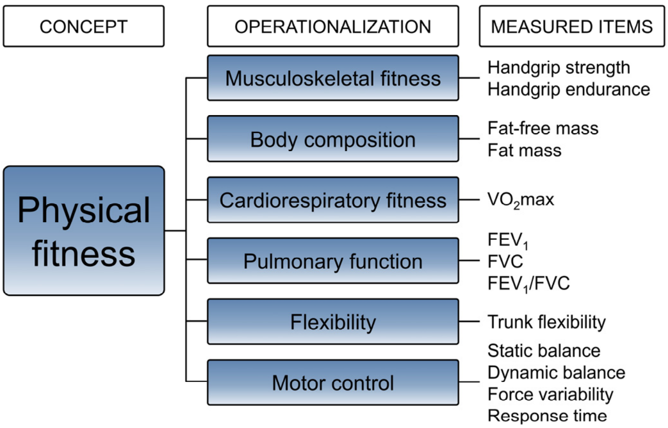

Figure 0-1. Definition of physical fitness within the thesis. *VO_2max, maximal rate of oxygen uptake; FEV1, forced expiratory volume after 1 s; FVC, forced vital capacity.*

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CHAPTER 1. INTRODUCTION

Across the world, people are living longer and by the year 2050, it is expected that one in every six people worldwide will be above the age of 65 years; in Europe, this number is one in four people (3). To accommodate the growing population of older adults, retirement age is currently being raised in many countries (4). This may be problematic for older workers in physically demanding occupations because physical work-demands stay at the same level regardless of age (5–7) and aging processes do not necessarily influence life expectancy. Although a decline in physical fitness with aging is probably inevitable (8), regular physical activity remains an important component in slowing the aging process (9). Does that mean that manual workers to some extent maintain their fitness by being in jobs in which they are physically active every day? Alternatively, does the daily strain of manual work exceed a threshold of adaptation thereby causing physical degeneration?

In this chapter it is outlined how aging leads to adverse outcomes and deconditioning of six important aspects of physical fitness. The effects of manual work upon these changes are thereafter described thereby building the theoretical framework on which the aims and hypotheses of the current thesis are constructed.

1.1. PHYSICAL FITNESS AMONG OLDER MANUAL WORKERS

Aging is a natural phenomenon affecting all species. In humans, the complex and heterogeneous process of aging involves several molecular, cellular, and organ system changes (10). Through an impaired ability to respond to stressors, aging also increases the susceptibility to diseases caused by external factors (11). Physical fitness–encompassing attributes related to both health and skill (2, 12)–gradually declines with aging. This process seems inescapable even in the absence of disease (8). Researchers are seeking out biomarkers of aging in an attempt to find a valid marker of *biological age* (13). To date, no single marker is able to predict the complex process of aging (14), but there does seem to be agreement that several aspects of physical fitness represent healthy aging (15–17).

1.1.1. MUSCULOSKELETAL FITNESS

Skeletal muscle strength and endurance play an integral part in daily life. Musculoskeletal fitness is fortunately among the most well preserved aspects of physical fitness with aging. However, with old age even opening a glass of jam or rising from a chair may become a challenge.

Maximal strength develops from childhood through adolescence and peaks around the early 30s (18). From thereon strength can be maintained to some extent until age 50–

at which time it inevitably starts to decline with annual rates of loss between 1-4% per year (19–22). Compared to muscle strength, power and the ability to produce rapid movements are lost at even faster rates (22, 23), whereas muscle endurance may be unchanged or even slightly increased before a decline is observed after age 70 (24). It is important to note that the rate of change can be greatly affected by exercise or inactivity. People who are initially sedentary may increase their strength by more than 50% if starting to exercise (18), thereby attaining their peak lifetime strength much later than age 30 (**Figure 1-1**). Although the response to exercise may be mitigated by old age (25), improvements can be seen even at very old ages (26). Contrary, acquiring an injury or musculoskeletal disorder could potentially accelerate the age-related decline in muscle strength. Unfortunately, below a certain strength threshold impairments in strength may start to interfere with activities of daily living and lead to disability (27–29). Indeed, low muscle strength is linked with greater risk of hospitalization (30) and mortality (15).

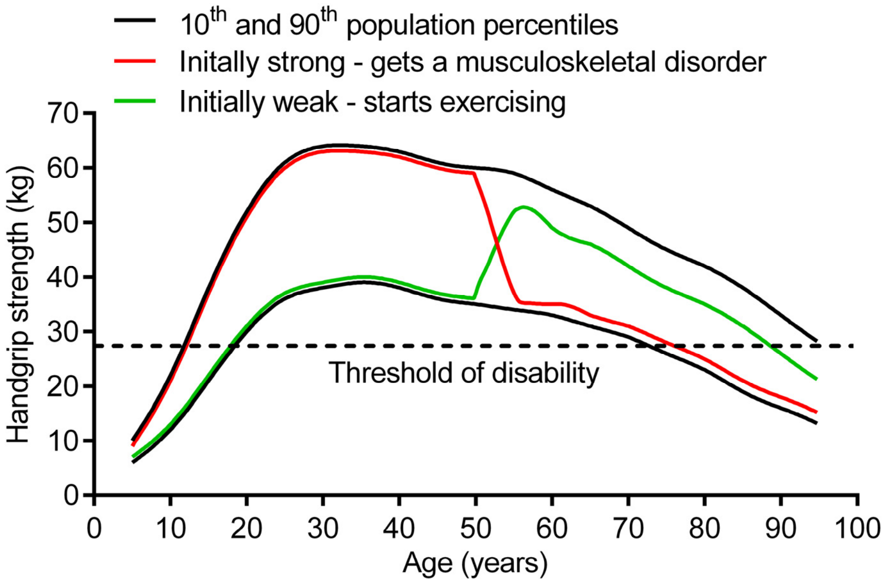

Figure 1-1. Changes in muscle strength across the life course. *The two black lines indicate 10th and 90th percentiles based on handgrip strength data for males from (31). The red line shows muscle strength across the life course of a person with high initial strength who acquires an injury or musculoskeletal disorder at age 50. The green line shows muscle strength across the life course of a person with low initial strength who starts exercising at age 50. The threshold of disability signifies the 27 kg cut-off value used to define sarcopenia among males* (32). *Adapted from (27).*

Manual work that continuously challenges the neuromuscular system should intuitively maintain musculoskeletal fitness more than sedentary work; however, conflicting evidence exists on this topic. Age-related reductions in muscle strength have been demonstrated in several manual occupations (33–35). Interestingly, maintained maximal strength with age (34) and greater strength compared with controls (35) have been observed thereby suggesting a protective effect of manual work. Contrary, others find no effect (36, 37) or even a detrimental effect (38) of manual work upon muscle strength. The low socioeconomic status associated with some manual professions could negatively affect strength in old age (39). Moreover, manual work may be characterized by static awkward postures, short recovery between bouts of activity, and poor worker control (40). The prevalence of musculoskeletal complaints is therefore particularly high among manual workers (41, 42). Thus, even if manual workers are initially strong at the beginning of their careers (43), muscle strength may not be maintained and could be negatively affected by manual work if workers acquire an injury or musculoskeletal disorder.

1.1.2. BODY COMPOSITION

The worldwide prevalence of obesity has increased over the last decades (44). The loss of skeletal muscle mass that accompanies aging has resulted in an older population suffering from sarcopenic obesity (45). Such changes in body composition are strongly related to negative health outcomes (46).

Although an age-related loss of muscle relative to total body mass may be observed from the early 20s, absolute changes in muscle mass probably occur starting around age 50 (47, 48). Annual rates of decline in muscle mass are estimated at about 0.5% per year (49), which notably is 2-5 times slower than that of muscle strength (19, 20). This process seems to accelerate with age (50)–with changes being especially pronounced in the lower extremities (48)–and the observed share of older adults with sarcopenia is about 40% in those aged over 80 years (45). Sarcopenia is associated with functional impairments and disability (51). Obesity may exaggerate this age-related loss of muscle mass through noninfectious inflammation (52). Indeed, visceral fat secretes adipokines such as interleukin 6 (IL-6) which is linked with systemic C-reactive protein (CRP) levels and chronic diseases (53). Interestingly, obesity seems to be a cause of disability among older adults even independently of chronic disease (54, 55). Among other explanations, the physical effort of having to carry around a body that is lacking in muscle mass and in excess of fat mass may be a reason for disability (56).

Knowledge on the effects of manual work on body composition is scant. An age-related increase in fat mass and a decrease in lean body mass has been observed among construction workers (34) and fire fighters (57). Similar to muscle strength (39), there is a social gradient in body composition changes (58). However, more muscle mass and less body fat was found for production compared with administrative workers in their fifties (59). In lack of further evidence, it could be speculated that muscle mass follows the same trajectory as that of muscle strength in manual workers, but further studies are warranted. Although a more indirect measure of adiposity, body mass index (BMI) has been used in several studies showing that obesity is prevalent among manual workers and about 65-70% can be classified as overweight or obese (56, 60).

Unhealthy behaviors such as high alcohol intake (61) and poor diet (62) among manual workers could potentially explain this. Importantly, obesity has a negative impact on work ability–especially when combined with high physical workloads (56).

1.1.3. CARDIORESPIRATORY FITNESS

Aerobic exercise performance is mainly determined by cardiorespiratory fitness (63). Although physical activity has a strong positive effect on cardiorespiratory fitness, it cannot completely eradicate the negative changes accompanying aging (64). Everyday tasks will therefore pose an increasingly greater relative aerobic strain as people age.

The loss of cardiorespiratory fitness–as measured by maximal oxygen consumption ($\dot{V}O_2max$)–that happens with aging may occur starting from the early 30s (65). Average annual reductions in $\dot{V}O_2max$ of 1% per year have been reported (66). Similar relative rates of decline are seen among sedentary and endurance-trained people (65), which could be due to a higher baseline $\dot{V}O_2max$ among active individuals. Nonetheless, $\dot{V}O_2max$ is still much greater in older adults with a history of aerobic exercise training compared with sedentary people (65, 67). The proposed mechanisms explaining the effect of old age on $\dot{V}O_2max$ are rooted in both central and peripheral adaptations. Maximal heart rate (HR) and stroke volume decreases with age (68, 69) and together these central adaptations reduces cardiac output and thus $\dot{V}O_2max$ (69). Peripheral adaptations include changes in body composition–mainly loss of muscle mass–and altered oxygen delivery and/or utilization by the muscle tissue (70). Cardiovascular diseases associated with aging may exacerbate these changes (71). Having a poor cardiorespiratory fitness level is independently predictive of all-cause and disease-specific mortality (72).

Age-related reductions in $\dot{V}O_2max$ have been observed among workers in physically demanding occupations such as power line workers (33), fire fighters (57), and construction workers (34). Although physical activity–especially physical exercise training–is known to improve cardiorespiratory fitness, occupational physical activity does not seem to have this effect (73, 74). It has been suggested that a physical activity health paradox exists (75), in which physical activities performed during work and leisure have opposing effects on health (76). One hypothesized reason for this is that occupational physical activity is of insufficient intensity to elicit a training response and that it instead may lead to cardiovascular disorders (40, 74). Interestingly, when comparing young with old waste collectors and young with old controls, a larger difference in $\dot{V}O_2max$ for the waste collectors than for controls has been observed (35). This difference could suggest an exaggerated decline in $\dot{V}O_2max$ among adults with physically demanding occupations in agreement with e.g. (74, 77, 78). Thus, although few studies exist, they suggests that manual work does not maintain cardiorespiratory fitness and that it may even be detrimental for some.

1.1.4. PULMONARY FUNCTION

Unlike cardiorespiratory fitness, pulmonary function is not normally a limiting factor for physical performance and function–nor does physical activity lead to any large improvements in pulmonary function (64, 79). Consequently, pulmonary function may not always be included as one of the aspects of physical fitness (2, 80). However, when age-related changes are coupled with some environmental exposures, pulmonary function may not only impede performance but may also increase risk of developing obstructive lung diseases (11).

In healthy non-smoking adults, changes in pulmonary function may be observed as early as the mid-20s (81). After age 30, forced vital capacity (FVC) and forced expiratory volume after one second (FEV_1) decrease at annual rates of about 0.6% and 0.8% per year, respectively (79, 82). These changes can be considerably exacerbated by environmental exposures such as tobacco smoking and dust exposure (83). Of interest, chronic obstructive pulmonary disease (COPD), although most often associated with environmental exposures, has been characterized as an «accelerated aging phenotype» (11). The primary mechanisms behind age-related impairments in pulmonary function are increased alveolar size, reduced chest wall compliance, and reduced respiratory muscle strength (84). While physical activity may not mitigate the effects of the two former, reductions in respiratory muscle strength can potentially be slowed by exercise (64, 85).

Manual workers such as cement workers, coal miners, and construction workers are frequently exposed to different dust as well as gases and aerosols that may cause pulmonary obstructive diseases (83, 86, 87). Such exposure may lead to a twofold increased risk of mortality from COPD (86). Moreover, unhealthy behaviors such as tobacco smoking is about twice as common among workers in physically demanding occupations compared with the general population (61). Interestingly, workers exposed to dust and chemicals at work are more likely to smoke (88). Tobacco smoke is the leading cause of COPD and the age-related decline in pulmonary function among manual workers may therefore be exaggerated by both environmental exposures and tobacco smoke (89).

1.1.5. FLEXIBILITY

Aging may reduce joint flexibility, thereby limiting functional range of motion (90–92). Although changes differ depending on the joint, decrements of about 0.5% per year have been reported (59, 92, 93). Stretching exercises improve flexibility and are therefore sometimes included as a part of public exercise recommendations (2). It has been speculated that greater flexibility may prevent injuries (94). For instance, more flexible hamstring muscles change the angle-torque relationship during knee flexion so that peak torques occurs at a greater joint angle (95). In other words, the muscles are stronger at longer muscle lengths. This could be of importance because strain injuries typically occur when muscles are maximally elongated (96). However, controversy exists on this topic (94, 96, 97) and the exact mechanisms through which stretching causes greater joint range of motion are still unknown (98). Perhaps more important for the non-athlete population, it is uncertain whether an increase in flexibility actually translates into improvements in physical fitness (94, 98); that is, a person's ability to perform physical activity and be in good health (2). Indeed, although flexibility training increases range of joint motion, it seems to have little effect on physical function (98).

Workers with high occupational physical loads may have poorer flexibility compared with those exposed to lower loads (99). A higher prevalence of osteoarthritis among such workers may contribute to this (100). For manual workers, it could be speculated that poor flexibility would lead to more restricted movements and awkward postures, which could possibly affecting work ability negatively. Moreover, it has been suggested that greater flexibility may help in reducing work-related musculoskeletal disorders among manual workers (101). Seemingly, impaired flexibility may predict the development of musculoskeletal pain (102). Among vineyard workers with low-back pain, strengthening and flexibility training not only improved trunk flexibility but also increased pain thresholds (103). How aging affects flexibility among older manual workers and how these changes relate to work ability is currently unknown.

1.1.6. MOTOR CONTROL

In humans, motor control–sometimes referred to as neuromotor fitness (2)–relates to the subjective control of movement tasks such as balance, accuracy, and gait (104). Coupled with a decline in muscle strength, changes in motor control can impair e.g. the ability to rise from a chair with old age (105). Unfortunately, reductions in strength among already weak adults have larger consequences on motor tasks compared with changes among stronger adults (28). Aging is moreover associated with greater motor variability (106), which can be observed during static muscle contractions where an increase in force variability with aging could suggest a loss of motor units (108). More variable movements with age can compromise postural steadiness–measured as an increase in the velocity of displacement during static standing–which may decrease by up to 2% per year with age (109, 110). These changes may be further exaggerated by musculoskeletal pain and disease (111–113). Moreover, slower information processing cause reaction times to slow by about 0.3% per year while also becoming more variable with old age (114, 115). Coupled with slower movements, response times ultimately slow down and start to affect the ability to respond to external stimuli (116) thereby playing a negative role on physical function (117). Together, poor motor control cause older adults to be at an increased risk of falls (118), disability (119), and mortality (15).

Manual workers frequently report musculoskeletal symptoms including fatigue and pain (42), which could affect their motor control (120). Interestingly, the stage of pain may have different effects on variability (121); at the acute stage, variability may increase as the motor system attempts to find a non-painful motor solution for a given task, while as pain starts to become chronic variability may decrease to avoid the painful solutions (122). Little is known about how these stages may interact with aging. Although sensory manifestations of pain can occur and motor control strategies may change after only a few months of employment into a manual profession (123), this does not necessarily lead to disability in early age. Following a life-time of manual work, however, even basic abilities such as getting up from a chair may be challenged (38, 124). Physical demands at work are indeed negatively related to physical function (125) and manual workers may therefore be at a greater risk of disability after retirement (126).

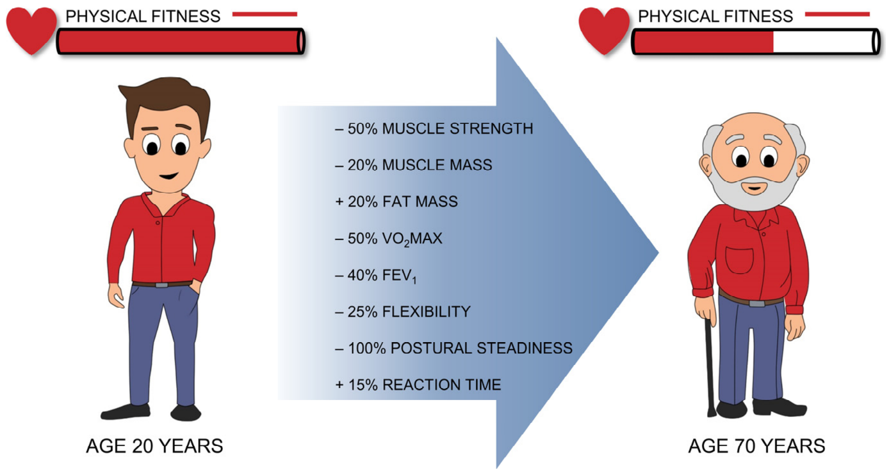

Figure 1-2. Effects of age on physical fitness. *Illustration of the effects of aging from an ideal 20 to 70 years on physical fitness. Values are approximates based on* (8, 47, 49, 66, 82, 92, 109, 115)*. VO_2max, maximal rate of oxygen uptake; FEV_1, forced expiratory volume after 1 s. Drawings credited to Øyvind Norheim.*

In summary, human aging inevitably leads to a gradual decline in physical fitness. Some domains of physical fitness may decline in a non-linear fashion possibly due to the effects of e.g. physical activity and musculoskeletal pain. On average, however, the physical fitness of a person aged 70 years may be about 60% that of their ideal 20 year old selves (**Figure 1-2**).

1.2. WORK ABILITY

Although many people maintain their ability to work until retirement, some still experience a decline–especially those with high physical work demands (127–129). Both old age and physically demanding work are negatively associated with work ability and older manual workers may therefore be particularly vulnerable to the impact of raising retirement age (130). Are old manual worker fit to work until retirement? An answer to this question is beyond the scope of the present thesis and is probably not dichotomous in nature. Nevertheless, before recommendations for future policies and interventions related to this question can be made, additional knowledge regarding the extent of change in physical fitness among older manual workers is needed. Indeed, people in physically demanding occupations are at an 18% increased risk of all-cause mortality compared with their sedentary counterparts (76), which signifies why this area of research is important (**Figure 1-3**).

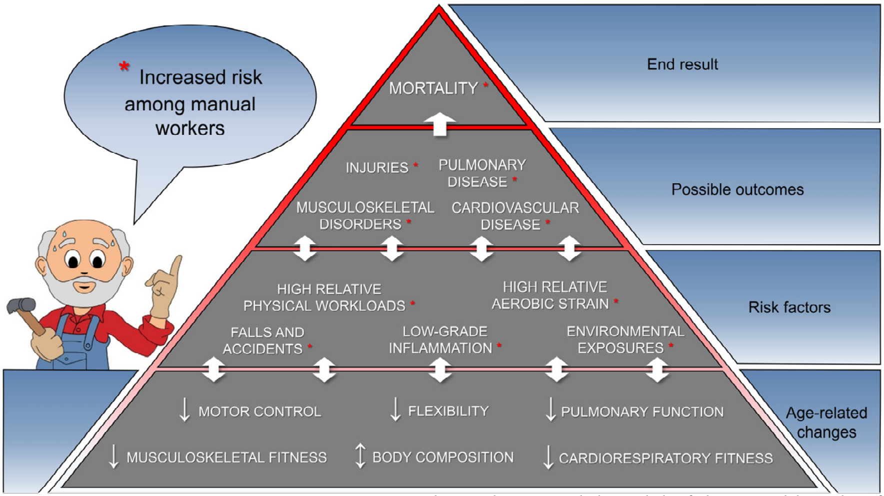

Figure 1-3. Aging and manual work. *Hypothetical pyramidal model of the possible role of manual work on age-related changes in physical fitness that may eventually end in mortality. Figure adapted from* (130) *and based on* (35, 38, 133–138, 42, 76, 77, 83, 100, 123, 131, 132). *Risk factors can be viewed as bidirectional; for example, age-related deficiencies in musculoskeletal fitness leads to higher relative physical workloads that may cause musculoskeletal disorders. Such disorders may increase relative physical workloads even further while also affecting musculoskeletal fitness. The bidirectional arrow besides body composition illustrates the age-associated increase and decrease in fat and muscle mass, respectively. Drawing credited to Øyvind Norheim.*

1.3. AIMS AND HYPOTHESES

The overall aim of this thesis was to investigate physical fitness among manual workers during the last two decades of working life. Further, it aimed to investigate the effects of musculoskeletal complaints on motor control tasks and fatigue development. To accomplish this, five studies were conducted. The aim of Study I was to create a study protocol to enhance transparency and reduce publication bias by selective reporting of research outcomes. The aim of Study II was to investigate the influence of age and stages of musculoskeletal pain (acute and chronic) on force variability during a sustained static contraction. The aim of Study III was to investigate the influence of age and acute musculoskeletal pain on lower extremity function and dynamic balance. The aim of Study IV was to investigate the influence of age on response time, accuracy, and motor control during a hammering task.

Finally, the aims of Study V were to investigate the extent of change in physical performances among older manual workers and to compare physical performances with general populations. This thesis is based on a study protocol (Study I) and four cross-sectional studies (Study II-V) as illustrated in **Figure 1-4**.

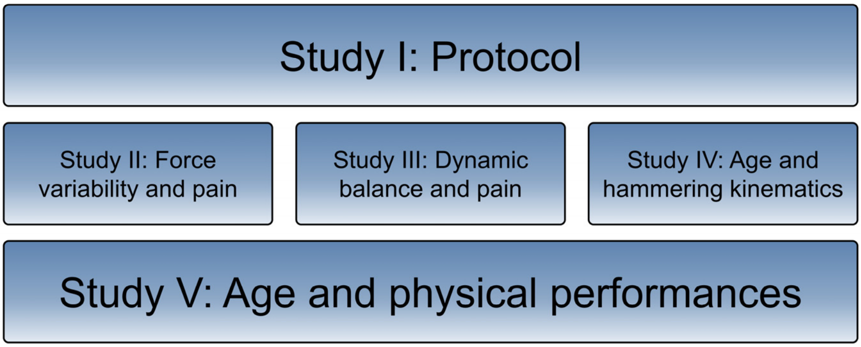

Figure 1-4. Included studies.

It was hypothesized that among manual workers, age would be associated with lower physical performances, larger force variability, poorer function and balance, and impaired response time. Thus, age was generally expected to be negatively associated with physical fitness among manual workers in their last two decades of working life. Musculoskeletal pain was expected to exacerbate the effects of age on motor control tasks and fatigue development.

CHAPTER 2. METHODS

The methodology used for this thesis is briefly outlined in this chapter. See Study I-V for more in-depth descriptions of the methods.

2.1. STUDY OVERVIEW

All experiments were carried out at the Laboratory for Ergonomics and Work-Related Disorders at Aalborg University, Aalborg, Denmark, between November 2017 and May 2019. The specific methods utilized for each of the four cross-sectional studies are presented in **Table 2-1**.

	Study II	Study III	Study IV	Study V
Questionnaire	✓	✓		✓
Blood samples				✓
Heart rate monitor				✓
Force dynamometry	✓			✓
Bioelectrical impedance analysis				✓
Spirometry				✓
Cycle ergometry				✓
Static posturography				✓
Dynamic posturography		✓		
3D motion capture			✓	

Table 2-1. Overview of methods used in Study II-V.

2.2. RECRUITMENT

This thesis was the third part of a larger project concerning older manual workers named the ALFA-project (Aldring og Fysisk Arbejde [Aging and Physical Work]). Given the recent raise in retirement age in Denmark, one of the major aims of the ALFA-project is to investigate attitudes toward retirement among manual workers (60). In Denmark, retirement age will from now on be regulated every five years based on life expectancy and at the inception of the ALFA-project only people born before 1967 were actually aware of the age at which they could retire. This corresponded to an age of 50 years in 2016 when the ALFA II questionnaire was sent out (see next section). The lower age limit for inclusion into the ALFA-project was therefore 50 years. An age-range encompassing two decades and including both current workers and retirees was chosen and the upper limit for inclusion was therefore 70 years (age range 50-70 years). The recruitment process for the ALFA III cohort, on which this thesis is built, has been described previously (Study I). Briefly, ALFA I is a register-based cohort of all citizens born before 1967 who (i) had worked in the construction industry after 1 January 2008, (ii) had been members of the United Federation of

Danish Workers (3F) or other relevant unions for manual workers for at least 2 years, and (iii) were registered in an unemployment insurance fund at the end of 2015. The ALFA II cohort is a randomly chosen sample of workers from the ALFA I cohort who answered a postal or online questionnaire. Workers who in this questionnaire indicated that they would like to participate a clinical examination of physical fitness were screened for eligibility. Exclusion criteria included previous neurological, musculoskeletal or mental illnesses and heart diseases that contradicted physical testing. Eligible workers were contacted first through e-mail and second by telephone when addresses were available. After being informed about the purpose of the study, workers who were still interested in participating were invited to an experimental testing session. Ninety-seven participants successfully arrived at the laboratory and completed the tests thus representing the ALFA III cohort (**Figure 2-2**). These participants were tested 1-2 years after the initiation of the ALFA-project and their age was therefore 51-72 years. Out of these, 66 participants were currently working and 31 participants had retired from a manual profession.

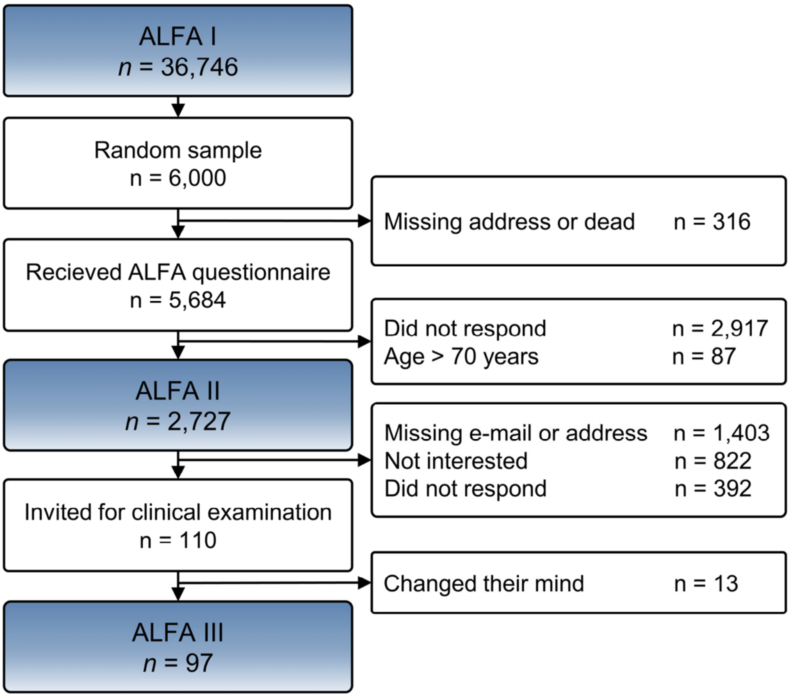

Figure 2-1. Flow chart of recruitment to the ALFA cohorts.

Gender-stratification could not be done in any studies because only one female worker ended up being part of the ALFA III cohort. Only males were therefore included in the analyses of the studies. Thus, in Study II and V, 96 male manual workers from the ALFA III cohort were included. Six participants in the ALFA III cohort did not complete the sit-to-stand (STS) test and Study III therefore includes 90 participants from the ALFA III cohort. In Study IV, only right-handed male participants asymptomatic of musculoskeletal symptoms in the upper extremities (139) were included from the ALFA III cohort (n = 23). Additionally in Study IV, sixteen young right-handed asymptomatic males were included to serve as a comparison group. These participants were staff and students at Aalborg University. Characteristics of the participants within Study II-V are shown in **Table 2-2**. All participants gave written and oral informed consent to participate after being informed about the purpose of the study, which was approved by The North Denmark Region Committee on Health Research Ethics (N-20160023) and carried out in accordance with the Declaration of Helsinki.

	Study II, V	**Study III**	**Study IV**	
			Young	Old
n	96[a]	90[a]	16	23[a]
Age (year)	60.5 ± 5.8	60.4 ± 5.8	29.1 ± 3.1	60.1 ± 5.6
Height (cm)	176.9 ± 6.7	177.0 ± 6.8	178.4 ± 5.8	178.2 ± 5.0
Body mass (kg)	88.0 ± 13.0	87.7 ± 13.1	80.2 ± 11.5	86.5 ± 10.6

Table 2-2. Participants within Study II-V. *Values are mean ± SD. [a]Participants of the ALFA III cohort.*

2.3. MEASUREMENTS OF PHYSICAL FITNESS

The methods used to measure physical fitness have been described in detail previously (Study I-V). A brief description of the battery of tests used on the ALFA III cohort follows. The test battery was designed to measure six important domains of physical fitness: musculoskeletal fitness, body composition, cardiovascular fitness, pulmonary function, flexibility, and motor control. The non-randomized order of the test-battery was chosen to ensure as little as possible carryover fatigue from previous tests. To validate this, heart rate (HR) data from 64 participants who wore HR monitors (Polar A300, Polar Electro Oy) throughout the test-battery starting from the pulmonary function test was used to calculate percent HR reserve to represent aerobic workload (140). Additionally, the Borg 6-20 scale (141) was used to assess inter-test ratings of perceived exertion (RPE). Although the length of the test-battery starting from the pulmonary function test varied between participants (mean ± SD, 80 ± 8 min), it was carried out in the same sequence for all participants. Changes in percent HR reserve across 20 time-normalized epochs of the test sequence with accompanying RPE are illustrated in **Figure 2-3**. Prior to the estimated $\dot{V}O_2max$ test, percent HR reserve was < 20%, which in agreement with the RPE corresponds to very light activity (80) and is lower than the occupationally induced aerobic workload seen among manual workers (77).

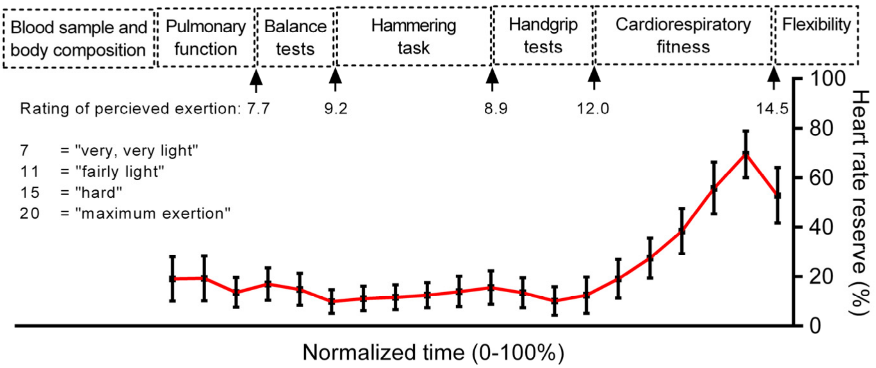

Figure 2-2. Test battery sequence. *Percent heart rate reserve and ratings of perceived exertion between physical tests and for the total test-battery are shown. Note that the heart rate monitor was started after the pulmonary function test. Values are mean ± SD. BIA, bioelectrical impedance analysis; HGS, handgrip strength; VO2max, maximal rate of oxygen uptake.*

2.3.1. MUSCULOSKELETAL FITNESS

A digital hand dynamometer (Model G100, Biometrics Ltd, Gwent, UK) was used to measure isometric maximal voluntary contraction (MVC) force and handgrip endurance in Study V and II, respectively (**Figure 2-4**).

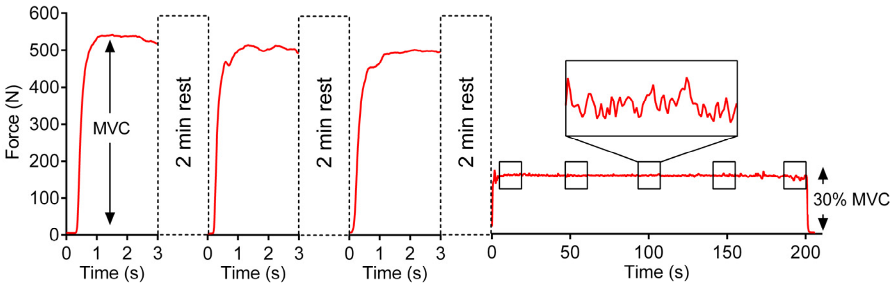

Figure 2-3. Handgrip tests. *Handgrip strength and endurance was included in Study V and II, respectively. Force variability was also included in Study II (see 2.3.6 Motor control). N, Newton; MVC, maximal voluntary contraction.*

For the MVC measurements in Study V, participants were asked to squeeze the dynamometer «as hard as possible» using their dominant hand (142). The highest force measured across three 3-s trials was defined as MVC. For Study II, following these trials, participants performed a fatiguing trial in which they were asked to maintain a force of 30% MVC for as long as possible. Visual feedback of the target force and the output force was provided on a computer screen in front of the participants. The trial ended when the force fell below 28% MVC for more than five consecutive seconds (see 2.3.6. Motor control). Two minutes rest were provided between all trials (142). For Study V, MVC was defined as maximal handgrip strength

(HGS) and was included as a measure of whole-body strength (143). Poor HGS has been related to cognitive impairments and disability (17, 29), mortality (15), and HGS is a reliable measure of muscle strength (144) even in patients with musculoskeletal symptoms (145).

2.3.2. BODY COMPOSITION

A direct segmental multi-frequency bioelectrical impedance analysis (BIA) machine (InBody 370, Biospace) was used to estimate body composition (146). Participants were advised not to exercise 24 h prior to the test and to avoid food intake for at least 2 h before arriving to the laboratory. No fluid intake restrictions were set prior to the test so as not to affect the results of the rest of the test-battery. Participants thoroughly wiped their feet and hands with alcohol swaps before stepping onto the machine. The test duration was ~45 s and imposed no invasiveness or discomfort. In a pilot study (147), we found high intra- and inter-day (48 hours between tests) reliability among 48 university students (age 20-28 years) for both fat percent and FFM (intraclass correlation coefficient > 0.9). Moreover, BIA is generally found to be a valid measure of body composition (148, 149) although less so when trying to estimate individual body compartments e.g. appendicular FFM (150). Thus, the outcomes whole-body FFM and fat percent were included in Study V.

2.3.3. CARDIORESPIRATORY FITNESS

The maximal rate of oxygen uptake ($\dot{V}O_2max$) was estimated using the Åstrand-Ryhming cycle ergometer test (151). Participants cycled on a bicycle ergometer (Ergomedic 874E, Monark AB, Varberg, Sweden) while wearing a Polar A300 HR monitor (Polar Electro Oy). After a brief 8-minute warm-up, resistance was gradually added until HR exceeded 120 bpm. The test was terminated once HR was stable within 4 bpm over a period of 2 min. Cardiorespiratory fitness, expressed as absolute ($L \cdot min^{-1}$) and relative ($ml \cdot kg^{-1} \cdot min^{-1}$) $\dot{V}O_2max$, was estimated from steady state HR and resistance (watt) using the computerized version of the Åstrand-Ryhming nomogram (152). These outcomes were included in Study V. The Åstrand-Ryhming test is widely used in both intervention studies e.g. (153) and large scale cohorts e.g. (154, 155) and seems to be a reliable and valid estimation of cardiorespiratory fitness (156). Although this submaximal test only estimates $\dot{V}O_2max$, maximal exercise tests using indirect calorimetry require extreme degrees of physical exertion and may not be feasible in older populations (157). This was further supported in the ALFA III cohort by eleven of the participants not even being able to complete the submaximal test due to premature exhaustion or musculoskeletal complaints.

2.3.4. PULMONARY FUNCTION

Pulmonary function was measured according to American Thoracic Society/European Respiratory Society guidelines (158). Disposable turbine flowmeters were attached to a Spirobank II SMART spirometer (Medical International Research [MIR], Rome, Italy). From a standing position, participants were instructed to fully inhale followed by a maximal expiration into the spirometer while wearing a nose clip. At least three acceptable trials had to be performed. Acceptable trials were defined by the MIR winspiroPRO software (version 6.5.0), which was used to calculate FEV_1 and FVC from each trial. In accordance with (158), the largest FEV_1 and FVC were recorded from trials independent of each other; that is, FEV_1 could potentially occur in a different trial than FVC. The FEV_1/FVC ratio was calculated from these recordings and together these three metrics were included as outcomes in Study V. A 3 L airtight syringe was used to calibrate the spirometer daily. When carried out according to published guidelines, spirometry is regarded as the gold standard for measuring pulmonary function (158).

2.3.5. FLEXIBILITY

Trunk flexibility was assessed using the fingertip-to-floor test, which is a reliable and valid test even in patients with musculoskeletal symptoms (159, 160). A custom-built box with a vertical beam attached to one side was used (103). The beam had a metal ruler with a movable magnet attached to it. Participants were instructed to stand on top of the box with their feet together and thereafter to bend forward. With their knees, arms, and fingers fully extended, they slowly pushed the magnet attached to the metal ruler down as far as possibly. Jerking movements were not allowed. The distance from the top of the box to the top of the magnet was noted. This distance could be both positive and negative (if pushed below the height of the box) and was included in Study V. Negative values express a larger range of motion.

2.3.6. MOTOR CONTROL

Static balance was measured using a force platform (AMTI AccuSway, Watertown, MA, USA). Participants were instructed to stand as quietly as possible while (i) keeping their eyes fixated on a spot at eye level one meter in front of them, (ii) keeping their eyes closed, and (iii) keeping eyes open and audibly counting out backwards from 30 to 0 by subtracting 3. Each condition lasted for 60 s and for the latter, participants restarted counting from 30 whenever they reached 0. For Study V, only the total mean velocity of sway during the eyes closed condition was included as a single measure to represent static balance in line with (109, 110).

Dynamic balance and lower extremity function were assessed using the five-repetition sit-to-stand (STS) test (161, 162). Participants were instructed to rise from a chair and sit back down «as fast as possible» for five consecutive repetitions with their feet on the force platform. Dynamic balance was expressed as the range, velocity, SD, maximal Lyapunov Exponent (LyE), and SaEn of center of pressure displacement in the anterior-posterior, medial-lateral, and free moment directions. LyE has previously been used in studies to assess postural stability (163) and may be used to identify people at risk of falls (164). SaEn has been used to quantify the complexity of physiological time-series (165) and is influenced by both age and musculoskeletal pain (166). Lower extremity function was expressed as total completion time, stand time, and sit time, as well as the rate of force development (RFD) in the upward and downward movement phases during the STS test. Dynamic balance and lower extremity function outcomes were included in Study III. Total completion time was also included as an outcome in Study V.

For study IV, a «Whack-a-mole» hammering task (Hammertime version 1.0, Aalborg University, Aalborg, Denmark) was implemented to assess response time, accuracy, and shoulder/arm kinematics. Participants stood in front of a computer monitor while holding a rubber mallet. On a table, which was adjusted to 20 cm below elbow height (167), lay a square force platform with nine points. The computer monitor showed a similar square with nine open circles. During the task, one of the open circles on the computer monitor turned black coupled with an auditory cue. The filled black circle randomly changed location every 1.8 s to one of the other nine open circles. Participants were instructed to hit the target on the force platform corresponding to target that turned black on the computer monitor as «quickly and accurately as possible». Active markers attached on the mallet, arm, and thorax of the participants were tracked by the Visualeyez II™ motion capture system set up with two VZ4000 trackers (Phoenix Technologies Inc., BC, Canada). The task lasted 120 s. The «Whack-a-mole» task was also tested on asymptomatic young adults. These participants were tested under the same conditions as the ALFA III cohort. For more details, see Study IV.

Force variability was assessed during the handgrip endurance test. For Study II, the standard deviation (SD), coefficient of variation (CV), and sample entropy (SaEn) of the force signal during the endurance trial was used to measure force variability as described by others (168–171). These metrics were measured over five epochs normalized between participants (**Figure 2-3**).

2.4. BLOOD SAMPLES

Systemic levels of CRP and IL-6 were used to control for inflammatory status in Study V. CRP levels seem unaffected by food intake (172–174), while diverging evidence exists for IL-6 showing either an increase (174) or a decrease (173) in postprandial levels possibly due to sampling procedures (175). However, food restriction in terms of fasting was not imposed to increase the feasibility of the study. Non-fasting venous blood samples were therefore collected from the antecubital vein into 6-mL ethylenediamine tetraacetic acid tubes. Following centrifugation, plasma was extracted and stored at -80 °C until analyzed for CRP and IL-6 levels using enzyme-linked immunosorbent assay kits. High levels of CRP and IL-6 are related to disability and mortality (15–17).

2.5. QUESTIONNAIRE

Answers to the ALFA II questionnaire was used to compare participants in the ALFA II and ALFA III cohorts in Study V. This was done to test the external validity and enable generalization of the clinical findings. Because these answers were more than one years old at the time of the ALFA III examinations, some of the ALFA II questionnaire was repeated for the ALFA III cohort (see Appendix in Study I).

In Study V, questions concerning smoking and leisure-time physical activity (176) were used as covariates. In Study II and III, questions from a modified Danish version of the Standardized Nordic Questionnaire (139) were used to stratify participants according to musculoskeletal symptoms in the upper and lower extremities, respectively.

In Study II, participants reporting > 3 months of pain within the last year while also reporting having a pain intensity > 3 on a scale from 0-10 within the last week in the upper extremities were defined as having chronic pain (177). Those with < 3 months of pain within the last year but who still had > 3 on a scale from 0-10 within the last week were defined as having acute pain. The rest of the participants were defined as having no pain in the upper extremities. This was done because there is evidence to suggest that changes in motor control are dependent on the stage of pain (121, 178).

In Study III, the effect of having pain in the lower extremities at the time of the sit-to-stand test was of interest. Therefore, participants were defined as having pain if they reported a pain intensity > 3 on a scale from 0-10 within the last week, regardless of pain duration within the last year. The robustness of the stratification was assessed by doing sensitivity analyses using both higher and lower levels of pain intensity as cut-off values.

Self-perceived physical work ability was assessed by a single-item question taken from the Work Ability Index (179), as described previously (60). Participants rated their physical work ability on a 5-point scale: poor, fair, good, very good or excellent. Retired workers were asked to respond to this question relating to the physical demands of their last held manual job.

2.6. DEVIATIONS FROM THE PROTOCOL

The aim of Study I was to create a study protocol to enhance transparency and reduce publication bias by selective reporting of research outcomes. However, issues arose after the protocol had been published which led to some slight deviations that warrant justification.

A power calculation was conducted to estimate the number of participants needed to attain a power of 0.8 for detecting a significant predictor variable a multiple regression analysis with either FEV_1 or FVC as the dependent variables and age, smoking status, and height as independent predictors. Based on equation 18 in (180), an estimated number of 102 participants was calculated. This number could not be reached because some of the invited participants changed their mind in the last minute.

RFD–which is a measure of explosive strength–was not calculated from the HGS trials because this measurement is sensitive to test instructions. Specifically, participants were instructed to contract «as hard as possible» because this typically leads to greater peak forces than «as fast as possible»; however, the opposite is found for peak RFD where the emphasis should be on the speed of the execution (142). The true peak RFD value was therefore probably not reached and was therefore not included.

In line with a similar study of force variability during isometric elbow flexion (171), 20% of MVC was considered as appropriate for the endurance handgrip test. Pilot testing indicated that some volunteers were able to hold this force for > 20 min which far exceeded the ~6 min seen in (171). Therefore, a higher force of 30% MVC was chosen as the target force for the endurance handgrip test to increase the feasibility of attaining a measure of performance fatigue rather than perceived fatigue (181).

During the hammering task, the force platform could not be used for reliable estimations of response time and accuracy because the sampling frequency of 100 Hz was too low. The motion capture system was instead used not only to track shoulder/arm kinematics, but also to estimate the hammer trajectory and thereby response time and accuracy.

2.7. STATISTICS

The statistics in the present thesis and within Study II-V were made using SPSS 25.0 (SPSS Inc., Chicago, Illinois, USA) and MATLAB versions R2018a and R2019a (The MathWorks Inc., Natick, MA, USA). In all studies, continuous outcomes were assessed for normality using the Shapiro-Wilk test and were log transformed if the criteria for normality were not met. Statistical significance was considered at $P < 0.05$.

In study II, the aim was to investigate the influence of age and stages of musculoskeletal pain (no pain, acute pain and chronic pain) on force variability. To accomplish this, full factorial analysis of variance models were created using time as the within-subject repeated factor and age and pain stage as between-subject factors. Age was used a fixed factor by dichotomizing between participants aged 50-59 years and 60+ years. The Bonferroni *post hoc* correction was applied for pairwise comparisons of significant factors.

In study III, the aim was to investigate the influence of age and acute musculoskeletal pain on lower extremity function and dynamic balance. A multiple linear regression model fitting the outcome measures was used to investigate the effect of age and pain. Between-subject factors age, pain, age × pain, and additionally work status (working/retired) and work status × pain were fitted to the models.

In study IV, the aim was to investigate the influence of age on response time, accuracy, and motor control during a hammering task. A linear mixed model fitting the outcome measures was used to investigate the effect of age (182). Target was added as a within-subject repeated factor in addition to the interaction term age × target. Subject was used to identify repeated measures and to define a random factor. The Bonferroni *post hoc* correction was applied for pairwise comparisons of significant factors.

In study V, the aims were to investigate the extent of change in physical performances among older manual workers and to compare physical performances with general populations. To accomplish this, linear regression models were created using age as the independent variable and performance outcomes as dependent variables. As suggested by Cole (183, 184), performance outcomes were log transformed and multiplied by 100 to assess the extent of percent change in performance per one-year increase in age expressed as β-coefficients and 95% confidence intervals (CI). This was done to enable comparisons between variables and with other studies. Models were progressively adjusted for covariates height, smoking status, leisure-time physical activity, CRP, and IL-6. The squared semi-partial correlation coefficient was calculated for all predictor variables in the fully adjusted models. Population differences in physical fitness were estimated by comparing outcomes with reference values from the general population of Denmark (185), United States (186), Norway (79), Switzerland (146), and Great Britain (31) using z-scores.

Additional analyses that had only been presented orally or in abstract form (187) were included in this thesis. Related to Study V, this involved analyzing the association between objectively measured physical fitness outcomes and subjectively measured physical work ability. Specifically, cumulative odds ordinal logistic regression with proportional odds was used (60) to assess the odds of reporting greater physical work ability based on these outcomes. Moreover, population differences in trunk flexibility that were not included in Study V are included in this thesis by comparing values with those of a relatively small study from Norway (93) using z-scores. Related to Study III, the interacting effects of age and pain on static balance during the three measured conditions were analyzed. Similar analyses to those in Study III were used, with the addition of a repeated measure analysis of variance to assess the effects of condition.

CHAPTER 3. RESULTS

The main results of Study II-V are presented in this chapter. Additional results that have only been presented orally or in abstract form are included. See Study II-V for more in-depth descriptions of the results.

3.1. HANDGRIP FORCE VARIABILITY AND PAIN (STUDY II)

Chronic and acute upper extremity pain was reported by 24% and 17% of the participants, respectively. Endurance time was 41.3 s longer for participants aged 60+ years compared with those aged 50-59 years. A significant effect of time on SD, CV and SaEn indicated a U-shaped change in SD and CV, and an inverted U-shaped change in SaEn across the endurance trial. No interactions between time × age, time × pain stage, or time × age × pain stage were observed. An age × pain stage interaction was found for SaEn, which revealed that participants aged 50-59 years with acute pain had larger SaEn than both those without pain and those with chronic pain within the same age group (**Figure 3-1**). Differences between age groups were only seen in the no pain and chronic pain groups with higher SaEn values in the 60+ years group. No effects of either age or pain were seen on SD and CV (Study II).

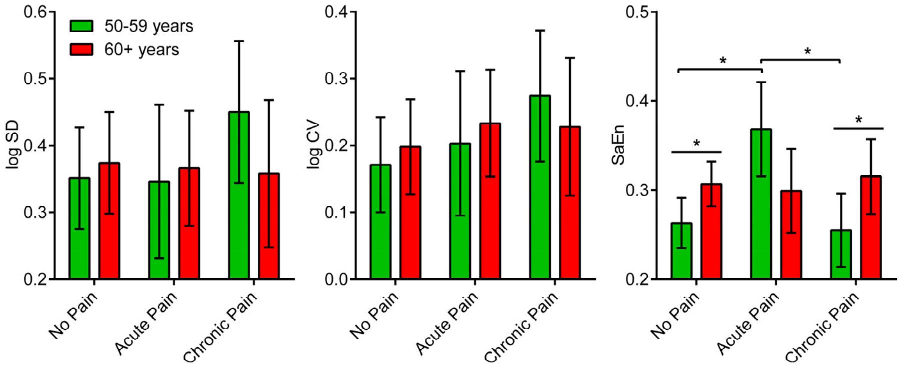

Figure 3-1. Age, pain stage, and handgrip force variability. *Note that SD and CV were not normally distributed and are presented on a logarithmic scale. Values are mean (95% CI).*P < 0.05. SD, standard deviation; CV, coefficient of variation; SaEn, sample entropy. Adapted from Study II.*

3.2. STATIC AND DYNAMIC BALANCE AND PAIN (STUDY III)

Lower extremity pain was reported by 47% of the participants. Interactions between age and pain indicated that lower extremity function was negatively related to age among participants without pain, but positively related to age among those with pain. The effects of work status were similar but generally smaller than the effects of age. Comparable findings were seen for dynamic balance (Study III). Although not included in Study III, analyses into the effect of age and pain on static balance found no age × pain interactions such as those seen for dynamic balance. For example, only a main effect of age was found for the total mean velocity of sway during three different static balance conditions. Notably, all conditions significantly differed from each other with the eyes closed condition showing the largest velocity of sway (**Figure 3-2**).

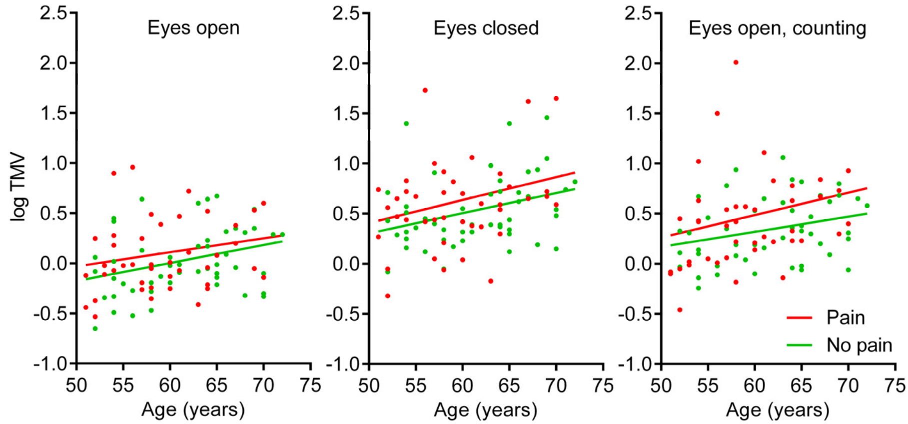

Figure 3-2. Age, pain, and static balance. *Total mean velocity of sway (TMV) during static standing with eyes open, eyes closed, and eyes open while counting backwards from 30 in multiples of three. Note that values were not normally distributed and are presented on a logarithmic scale. Individual values are shown as dots with lines representing linear regression lines for participants with (red) and without (green) lower extremity musculoskeletal pain.*

3.3. AGE AND HAMMERING KINEMATICS (STUDY IV)

The older manual workers had response times about twice that of the young participants as illustrated by none of the mean response times overlapping between age groups (**Figure 3-3**). No marked differences in hammering accuracy were observed. Despite these findings, the old participants utilized a hammering strategy wherein they had less hammer displacement and shoulder range of motion, effectively decreasing the biomechanical load (Study IV).

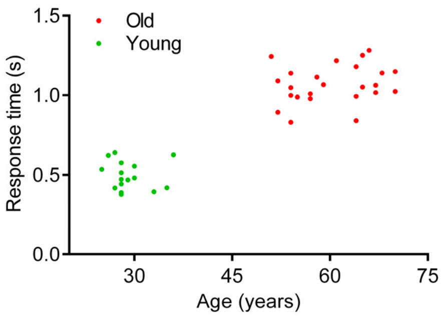

Figure 3-3. «Whack-a-mole» response times for young and old participants. *Mean values across all nine targets are shown for each individual. Adapted from Study IV.*

3.4. AGE AND PHYSICAL PERFORMANCES (STUDY V)

Demographics of the ALFA II and ALFA III cohorts did not markedly differ except for a greater proportion of bricklayers in the latter cohort (Supplementary material in Study V).

For most aspects of physical fitness, a negative association was found with age except for static balance for which a positive association indicated larger postural perturbations (poorer balance) with aging. In the fully adjusted models, age explained only a small part of the variance in fitness, whereas a larger part was explained by smoking and CRP. An illustration of the results from the simple linear regression analyses can be seen in **Figure 3-4**.

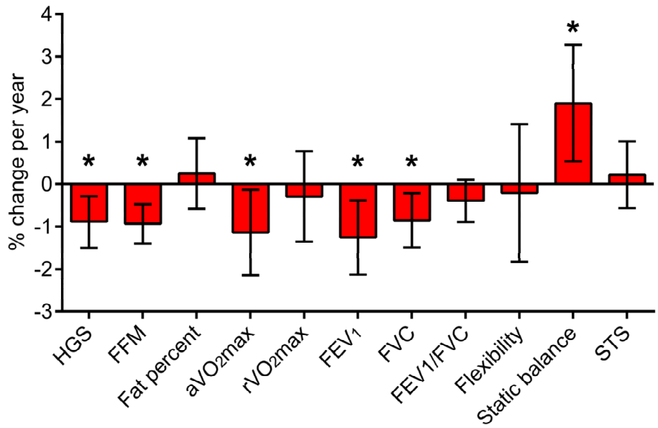

Figure 3-4. Estimated percent change in physical fitness based on age. *Values are β-coefficients with 95% CI. *P < 0.05. HGS, handgrip strength; FFM, fat-free mass; VO2max, maximal rate of oxygen uptake; FEV1, forced expiratory volume after 1 s; FVC, forced vital capacity; STS, sit-to-stand. Adapted from Study V.*

Comparisons with reference populations indicated that the included manual workers had higher BMI, HGS, FFM, and fat percent, but lower FEV_1/FVC and both absolute and relative $\dot{V}O_2max$ (Study V). Moreover, trunk flexibility was poorer for both the 50-59 years (z-score 6.05, $P < 0.05$) and 60-69 years (z-score 7.45, $P < 0.05$) age groups when compared with reference values from Norway.

An increase in FFM was associated with a decrease in the odds of reporting excellent physical work ability among participants aged 50-59 years. Contrary, an increase in HGS, FFM, absolute $\dot{V}O_2max$, FEV_1, and FVC was associated with an increase in the odds of reporting excellent physical work ability, whereas increased fat percent and flexibility (larger values express poorer flexibility) was associated with decreased odds of reporting excellent physical work ability among participants aged 60+ years (**Figure 3-5**).

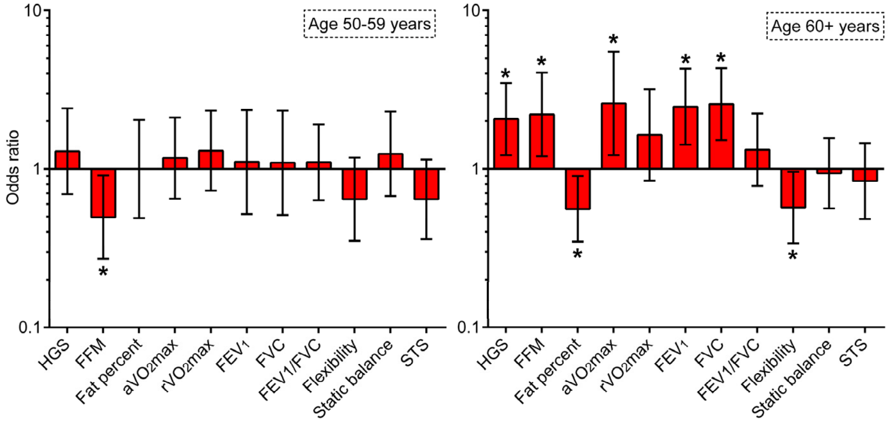

Figure 3-5. Physical work ability and physical fitness. *Shown are odds ratios (95% CI) of reporting greater physical work ability based on z-scores of physical fitness outcomes. *P < 0.05. HGS, handgrip strength; FFM, fat-free mass;* VO_2max*, maximal rate of oxygen uptake;* FEV_1*, forced expiratory volume after 1 s; FVC, forced vital capacity; STS, sit-to-stand.*

3.5. SUMMARY OF MAIN RESULTS

An overview of the main results from Study II-V is presented in **Figure 3-6**. Overall, negative associations were seen between most of the measured items of physical fitness and either age, manual work, or musculoskeletal pain.

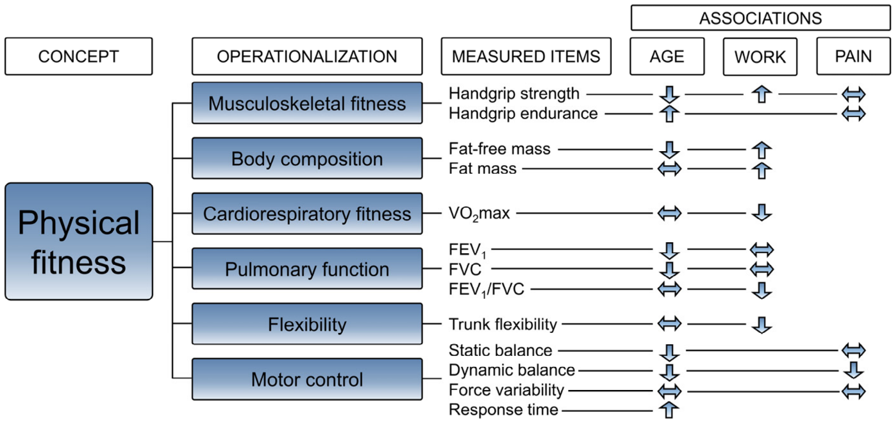

Figure 3-6. Overview of the main results from Study II-V. *Associations denotes the isolated relationships between age, work (manual workers vs. general populations), or pain (musculoskeletal pain) on the measured items of physical fitness. Downward, upward and horizontal arrows represent positive, negative, and no marked associations, respectively. For example, handgrip strength was positively associated with age; manual workers were stronger than general populations; and musculoskeletal pain had no marked effect on handgrip strength. For static and dynamic balance, downward arrows indicate poorer performances (larger perturbations with age and pain).* VO_2max*, maximal rate of oxygen uptake; FEV1, forced expiratory volume after 1 s; FVC, forced vital capacity.*

CHAPTER 4. DISCUSSION

Findings of the included studies have been discussed in detail previously (Study II-V). In this chapter, it is attempted to collect all these findings and to compare them against the weight of the evidence already present in the literature. Moreover, a number of mechanisms explaining these findings are suggested followed by some general strengths and limitations of the thesis. Lastly, conclusions are made based on these findings and perspectives and strategies for future investigations are suggested.

4.1. PHYSICAL FITNESS AMONG OLDER MANUAL WORKERS

Aging leads to a decline in physical fitness and exercise training is known to attenuate this change. Based on the findings of this thesis and other studies (75, 76, 188), manual work does not necessarily have the same benefits. A number of mechanisms may explain this conflicting association between physical fitness and either exercise training or occupational physical activity (40).

4.1.1. MUSCULOSKELETAL FITNESS

Handgrip strength was greater and showed a slower rate of decline with age compared with general populations (Study V). Manual workers being stronger than other workers is in agreement with some (35, 43, 99, 189) but far from all studies (36–38, 73, 125, 190–193). Notably, acute or chronic upper extremity complaints had no marked effect on HGS (Study II), indicating that greater strength may not necessarily protect against musculoskeletal symptoms, or reversely that pain may not necessarily affect maximal strength. Handgrip endurance was longer among the oldest workers (Study II) in agreement with other findings using relative loading (194, 195).

Resistance training is currently the most effective way to counteract the negative effects of age on muscle strength (196). Maximal muscle strength is diminished after an acute bout of heavy resistance exercise and following a period of recovery–typically 2-3 days–strength levels return to normal or a higher level (197). If chronic bouts of progressive resistance training are undertaken, maximal strength will increase over time (198). Manual work may differ from this model of adaptation in several ways. First, the acute physiological effects of a workday are currently unknown and probably differ from those of a 1-h resistance exercise session. Second, recovery is usually only from the end of the workday until the beginning of the next (~16 h). Third, resistance is not necessarily progressive; for instance, the weight of a hammer does not change. It thus seems unlikely that manual work increases musculoskeletal fitness similar to resistance training. However, the slow rate of decline with age in muscle strength found in this thesis lends credence to the belief that manual work to some extent may maintain muscle strength. Importantly, whether manual work maintains muscle strength will depend on the work tasks performed. The apparent discrepancy between studies on the effect of manual work on e.g. HGS could therefore be related to the extent of heavy gripping performed in different types of manual work. In other words, a bricklayer may maintain HGS whereas a power line worker may maintain overhead lifting strength (33). It is also possible that people who go into manual professions have a genetic predisposition to physically challenging work by being bigger and stronger than other people are from early adulthood (43). Indeed, if manual workers have a high initial muscle strength it requires much less volume and effort to maintain strength levels (199).

4.1.2. BODY COMPOSITION

Higher BMI was found compared with general populations (Study V) and about 70% of the manual workers were classified as overweight or obese in the ALFA II cohort (60) in agreement with (56). Possible misclassifications due to higher absolute FFM (a proxy for muscle mass) could contribute to this such as seen in very physically active populations (200); however, fat percent was also higher suggesting a relationship between manual work and excess body fat. Contrary to the effect of manual work, age was associated with a decline in FFM, but not related to changes in fat percent (Study V).

Aging leads to changes in body composition including reduced muscle mass and increased fat mass (45). In the short term, changes in muscle and fat mass are primarily regulated through physical exercise and energy balance (201). Whilst resistance training may lead to muscle hypertrophy (202, 203), inactivity and immobilization causes muscle atrophy (204, 205). Thus, similar to muscle strength, there may be a genetic component to older manual workers having higher FFM compared with general populations. Contrary to FFM, fat mass is less affected by exercise. Fat mass decreases under hypocaloric conditions and increases when calories are in excess (206). Although physical activity can increase total energy expenditure, compensatory mechanisms may increase hunger and energy intake thereby maintaining total body mass (201). Consequently, changes in fat mass are typically achieved through dietary intervention. The mechanism by which manual workers seem to have greater fat percent compared with other populations could therefore be differences in dietary patterns. Unhealthy diets often goes in concert with other unhealthy behaviors seen among manual workers such as high alcohol intake and smoking (61, 62).

4.1.3. CARDIORESPIRATORY FITNESS

Although one study has shown a positive association between heavy manual work and higher cardiorespiratory fitness among young workers (43), most other studies indicate that $\dot{V}O_2max$ is not improved by doing manual work (33–35, 57, 73, 77, 78, 99, 193, 207). In lack of prospective studies, it is uncertain whether manual work actually causes degeneration of cardiorespiratory fitness. Nevertheless, there is no compelling evidence to suggest that manual work improves cardiorespiratory fitness and the findings in Study V strengthens this assumption.

The age-related loss of cardiorespiratory fitness can to some extent be mitigated following short but chronic bouts of aerobic exercise (65, 67, 208). Although recommendations for optimal exercise intensities are normally around 65% HR reserve (209), positive adaptations may occur over a wide range of intensities (210). Given that the average aerobic intensity during a day of manual work may be about 25-40% HR reserve (74, 77), some have hypothesized that the intensity during work is insufficient to improve cardiorespiratory fitness (40). However, the minimal threshold intensity for improving cardiorespiratory fitness may be as low as 30% HR reserve for individuals with $\dot{V}O_2max$ values below 40 $ml \cdot kg^{-1} \cdot min^{-1}$ (211). In Study V, $\dot{V}O_2max$ values were generally less than 30 $ml \cdot kg^{-1} \cdot min^{-1}$ similar to findings among construction workers (153), fire fighters (57), and municipal workers with high perceived workloads (73). Based on these findings, it could be speculated that aerobic intensities are indeed not too low and could both maintain and improve $\dot{V}O_2max$. Because this does not seem to be the case, other mechanisms may explain why there does not seem to be a training or maintaining effect of doing manual work on cardiorespiratory fitness–possibly related to duration and recovery (40). Notably, other exposures such as tobacco smoke may also influence $\dot{V}O_2max$ negatively (212). This relationship was not seen in Study V possibly due to a lack of statistical power.

4.1.4. PULMONARY FUNCTION

About 30% of the older manual workers had a pulmonary function below the lower limit of normal for Danish males of similar age and height (Study V). Still, without information about the working environment of the participants only speculations may be made regarding the effect of manual work on pulmonary function.

Considering that exercise has very little effect on the lungs (64, 79), the most effective way to maintain pulmonary function is to avoid environmental exposures such as dust and pollution, and to abstain from tobacco smoke (89). Surprisingly, leisure-time physical activity explained the largest amount of variance in pulmonary function (Study V). This could possibly be due to reversed causation wherein physical activity is lower among those with poor pulmonary function. Because manual workers typically smoke more tobacco than other people (61) and may–depending on the occupation–be exposed to environmental toxins (83), manual work may both directly and indirectly cause degeneration of pulmonary function. Similar to unhealthy diets, it is uncertain why people in physically demanding occupations use more tobacco. Some have suggested that the concern for the negative effects of smoking is reduced because of an omnipresent concern for work related hazards (61). In addition, there may be a socioeconomic gradient to these findings, wherein social inequalities contribute to manual workers engaging in such unhealthy behaviors (213). Therefore, the combination of age-related changes coupled with life-style factors and environmental exposures could potentially explain the poor pulmonary function among older manual workers.

4.1.5. FLEXIBILITY

Trunk flexibility was not associated with age (Study V), which is contrary to that seen in other populations (59, 90–92). Compared with reference values, average flexibility was poorer and resembled that of 70 to 80 year olds (93). Thus, it does not seem like manual work improves flexibility.

Age-related changes in flexibility may to some extent be counteracted by stretching exercise (2). Given that manual work bears little resemblance with stretching exercise, it was not expected that manual work would maintain or improve flexibility. Indeed, some find poorer flexibility among those with high occupational physical workloads compared with those exposed to lower loads (99), whereas others have found no effect of manual work on trunk flexibility (190). The reason for not finding an effect of age on flexibility (Study V) could be that lower levels of musculoskeletal pain in the oldest workers (Study II) mitigated the effects of age. Alternatively, noticeable reductions in trunk flexibility may start as late as in the 70s (93) and the cohort may therefore have been too young to detect such changes.

4.1.6. MOTOR CONTROL

Response times in a task that, at least for carpenters, one might expect to be familiar to older manual workers were twice that of younger controls (Study IV). This could be explained by both a decline in motor control and cognitive processing. Contrary to some findings (106, 214), the amplitude of force variability was not related with age or pain (Study II). Furthermore, similar to STS performance (Study III), the structure of force variability seemed affected by acute pain only among workers aged 50-59 years (Study II). STS performance was moreover poor compared with reference values (Study III) in agreement with (124). The velocity of postural sway was positively associated with age, which possibly indicated more instability among older workers (Study V). Unlike the structure of force variability and dynamic balance, static balance did not seem affected by musculoskeletal pain (findings not reported in Study II-V).

Musculoskeletal pain affects postural control and motor variability (113, 120, 215–217). The lack of a clear effect of pain on static balance and the amplitude of force variability during a static contraction could be due to the relatively low pain levels compared with others (216, 217). For a dynamic task such as rising from a chair, however, musculoskeletal pain levels may be exacerbated compared with static tasks and thereby become high enough to impede performance (Study III). Regarding the effects of age, both static and dynamic motor control tasks seemed affected (Study II-

IV) suggesting global motor performance deficits in these older manual workers (104).

4.2. WORK ABILITY

A somewhat surprising relationship between higher FFM and poorer physical work ability among workers aged 50-59 years was found. The opposite and more expected association was seen for those aged 60+ years. It is possible that in the 50-59 years workers, a large total body mass–regardless of body composition–has a negative effect on work ability. Indeed, the combination of a large body mass and high physical workloads have synergistic negative effects on work ability (56). For the oldest workers, however, age-related changes may have reduced muscle mass to such an extent that having too low levels may start to impose negative effects on work ability. Indeed, it seemed like most aspects of physical fitness were associated with self-perceived physical work ability only after age 60 (187). This could suggest that physical fitness becomes a limiting factor for physical work ability only in the oldest manual workers. The ability to perform the physical demands at work may therefore become difficult with an increase in retirement age. It should be mentioned, however, that beyond physical factors, good work ability relies on both psychological and social aspects not addressed in the present thesis (218). Moreover, given that about half of the workers aged 60+ years had retired, the perception of their physical work ability related to the physical demands of their last held manual job may have changed since retirement.

4.3. STRENGTHS AND LIMITATIONS

To the author's knowledge, the present thesis provides the most extensive assessment to date of different aspects of physical fitness in manual workers aged 50 years and older. The protocol paper (Study I) and the use of state-of-the-art methods for measuring physical fitness strengthens the findings of this thesis. Given the similarity between the ALFA II and ALFA III cohorts (Study V)–the former being a random sample–the findings are considered to have high external validity towards Danish male manual workers in their last two decades of work. A number of limitations still need to be addressed.

First, the cross-sectional nature of the included studies limits interpretations to associations. The possibility of a healthy worker effect–where only the most physically fit workers remain in the workforce–could have underestimated changes in physical fitness. However, by including both current workers and retirees, this effect was probably reduced. This was supported by no marked differences between the demographics of the ALFA II and ALFA III cohorts (Study V).

Second, stratifications based on profession was not done in any of the studies due to the relatively small sample size. Potentially interesting differences between workers with e.g. high upper- vs. lower-body physical exposure was therefore missed.

Third, the effects of gender could not be addressed, which limits the generalizability of the findings. It was attempted to recruit both men and women, but only one woman was tested as a part of the ALFA III cohort. However, a similarly small proportion (2%) of the ALFA II cohort were women (Study V, Supplementary Information) suggesting that this represents the current landscape in terms of gender distribution among older manual workers in Denmark.

Lastly, it is acknowledged that the concept of «age» varies depending on its preceding adjective–e.g. psychosocial, organizational, biological (1)–and that in the current thesis, *age* was defined only as chronological age (time since birth). Other definitions may have yielded results different to those presented here.

4.4. CONCLUSIONS

The present thesis sought to address the issue of an aging workforce. Specifically, physical fitness among manual workers during the last two decades of working life was investigated.

Study I set the scene for the thesis as a whole. Results from Study II demonstrated that age and the stage of musculoskeletal pain differentially affects the structure of handgrip force variability in manual workers. Study III showed an age-dependency on the effects of musculoskeletal pain on lower extremity function and dynamic balance. Study IV found that response times during a hammering task were markedly slower for older manual workers compared with younger controls, which was not accompanied with differences in accuracy. Finalizing the thesis, results from Study V indicated that physical fitness deteriorates with aging in manual workers. Greater handgrip strength and body size, but poorer cardiorespiratory fitness and pulmonary function was found compared with general populations.

In summary, the present thesis indicated that manual workers do not improve their fitness by being in jobs in which they are physically active every day. Especially cardiorespiratory fitness, pulmonary function, and motor control seemed to be negatively affected, whereas handgrip strength may be maintained to some extent in these older workers. Of note, physical fitness was more strongly associated with physical work ability after age 60, suggesting physical fitness as a limiting factor only among the oldest workers. The frame of the findings are limited by the cross-sectional nature of the studies. Hence, no causal conclusions can be made as to whether manual work maintains or degrades physical fitness.

4.5. PERSPECTIVES

Workers in physically demanding occupations report that they could potentially stay longer in the workforce if physical work demands were reduced (219). Ergonomic interventions such as lift-assist devices have been incorporated in several manual occupations and it may not be feasible to reduce work demands further (220). An alternative way to decrease physical workloads could therefore be to decrease total body mass (56)–especially in professions that involve large amounts of locomotion (e.g. waste collection, cleaning, construction work). Considering that 65-70% of manual workers can be classified as overweight or obese (56, 60), weight loss may be a potential target for future interventions among manual workers. Reducing body mass would also improve cardiorespiratory fitness i.e. *relative* ($ml \cdot kg^{-1} \cdot min^{-1}$) $\dot{V}O_2max$.

The «Goldilocks principle» was recently proposed as a solution for promoting health and work ability (221). The principle suggests that work demands should be changed so that workers improve their physical fitness by working. Considering the huge variability in response to exercise (222) and the large amount of variables to be considered for optimal exercise programming even in controlled settings (2, 198, 223, 224), this vision seems unlikely both from a physiological and organizational viewpoint. Well-controlled interventions that actively improves physical fitness may therefore be needed, incorporated into either the workday or leisure. Previous studies have found favorable–albeit moderate–results of workplace physical exercise interventions on physical fitness among some groups of workers (225). In lack of age-stratified studies, it is currently unknown whether such interventions would improve physical fitness among older manual workers specifically. Moreover, a more thorough understanding of the physiological responses to manual work is needed. Investigations into the intramuscular and biochemical effects of a physically demanding workday could potentially help to elucidate whether manual work maintains or deteriorates physical fitness.

REFERENCES

1. De Lange A, Taris T, Jansen P, et al. Age as factor in the relation between work and mental health: Results of the longitudinal TAS survey. *Occup Heal Psychol Eur Perspect Res Educ Pract*. 2006;1:21–45.

2. Garber CE, Blissmer B, Deschenes MR, et al. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: Guidance for prescribing exercise. *Med Sci Sports Exerc*. 2011;43(7):1334–59.

3. United Nations, Department of Economic and Social Affairs PD. World Population Prospects 2019. 2019;Volume I: Comprehensive Tables.

4. He W, Goodkind D, Kowal P. *An aging world: 2015*. Washington, DC: U.S. Government Publishing Office; 2016.

5. Lusa S, Louhevaara V, Kinnunen K. Are the job demands on physical work capacity equal for young and aging firefighters? *J Occup Med Off Publ Ind Med Assoc*. 1994;36(1):70–4.

6. Sluiter JK. High-demand jobs: age-related diversity in work ability? *Appl Ergon*. 2006;37(4):429–40.

7. de Zwart BC, Frings-Dresen MH, van Dijk FJ. Physical workload and the aging worker: a review of the literature. *Int Arch Occup Environ Health*. 1995;68(1):1–12.

8. Sehl ME, Yates FE. Kinetics of human aging: I. Rates of senescence between ages 30 and 70 years in healthy people. *J Gerontol A Biol Sci Med Sci*. 2001;56(5):B198-208.

9. Booth FW, Roberts CK, Laye MJ. Lack of exercise is a major cause of chronic diseases. *Compr Physiol*. 2012;2(2):1143–211.

10. Aunan JR, Watson MM, Hagland HR, Søreide K. Molecular and biological hallmarks of ageing. *Br J Surg*. 2016;103(2):e29–46.

11. Sharma G, Hanania NA, Shim YM. The aging immune system and its relationship to the development of chronic obstructive pulmonary disease. *Proceedings of the American Thoracic Society*. 2009. p. 573–80.

12. Caspersen C, Powell K, Christenson G. Physical activity, exercise, and

physical fitness: definitions and distinctions for health-related research. *Public Heal Rep*. 1985;100(2):126.

13. Karasik D, Demissie S, Cupples LA, Kiel DP. Disentangling the genetic determinants of human aging: biological age as an alternative to the use of survival measures. *J Gerontol A Biol Sci Med Sci*. 2005;60(5):574–87.

14. Ingram DK, Nakamura E, Smucny D, Roth GS, Lane MA. Strategy for identifying biomarkers of aging in long-lived species. *Exp Gerontol*. 2001;36(7):1025–34.

15. Wagner K-H, Cameron-Smith D, Wessner B, Franzke B. Biomarkers of Aging: From Function to Molecular Biology. *Nutrients*. 2016;8(6):338.

16. Lara J, Cooper R, Nissan J, et al. A proposed panel of biomarkers of healthy ageing. *BMC Med*. 2015;13(1):222.

17. Martin-Ruiz C, Jagger C, Kingston A, et al. Assessment of a large panel of candidate biomarkers of ageing in the Newcastle 85+ study. *Mech Ageing Dev*. 2011;132(10):496–502.

18. Vandervoort AA. Aging of the human neuromuscular system. *Muscle Nerve*. 2002;25(1):17–25.

19. Goodpaster BH, Park SW, Harris TB, et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. *J Gerontol A Biol Sci Med Sci*. 2006;61(10):1059–64.

20. Delmonico MJ, Harris TB, Visser M, et al. Longitudinal study of muscle strength, quality, and adipose tissue infiltration. *Am J Clin Nutr*. 2009;90(6):1579–85.

21. Frontera WR, Hughes VA, Fielding RA, Fiatarone MA, Evans WJ, Roubenoff R. Aging of skeletal muscle: a 12-yr longitudinal study. *J Appl Physiol*. 2000;88(4):1321–6.

22. Skelton DA, Greig CA, Davies JM, Young A. Strength, power and related functional ability of healthy people aged 65-89 years. *Age Ageing*. 1994;23(5):371–7.

23. Izquierdo M, Ibañez J, Gorostiaga E, et al. Maximal strength and power characteristics in isometric and dynamic actions of the upper and lower extremities in middle-aged and older men. *Acta Physiol Scand*. 1999;167(1):57–68.

24. Justice JN, Mani D, Pierpoint LA, Enoka RM. Fatigability of the dorsiflexors and associations among multiple domains of motor function in young and old adults. *Exp Gerontol*. 2014;55:92–101.

25. Kosek DJ, Kim J-S, Petrella JK, Cross JM, Bamman MM, Bamman MM. Efficacy of 3 days/wk resistance training on myofiber hypertrophy and myogenic mechanisms in young vs. older adults. *J Appl Physiol*. 2006;101(2):531–44.

26. Kryger AI, Andersen JL. Resistance training in the oldest old: consequences for muscle strength, fiber types, fiber size, and MHC isoforms. *Scand J Med Sci Sports*. 2007;17(4):422–30.

27. Kalache A, Kickbusch I. A global strategy for healthy ageing. *World Health*. 1997;50(4):4–5.

28. Buchner DM, Larson EB, Wagner EH, Koepsell TD, De Lateur BJ. Evidence for a Non-linear Relationship between Leg Strength and Gait Speed. *Age Ageing*. 1996;25(5):386–91.

29. Rantanen T, Guralnik JM, Foley D, et al. Midlife hand grip strength as a predictor of old age disability. *Jama*. 1999;281(6):558–60.

30. Cawthon PM, Fox KM, Gandra SR, et al. Do muscle mass, muscle density, strength, and physical function similarly influence risk of hospitalization in older adults? *J Am Geriatr Soc*. 2009;57(8):1411–9.

31. Dodds RM, Syddall HE, Cooper R, et al. Grip strength across the life course: normative data from twelve British studies. *PLoS One*. 2014;9(12):e113637.

32. Cruz-Jentoft AJ, Bahat G, Bauer J, et al. Sarcopenia: Revised European consensus on definition and diagnosis. *Age Ageing*. 2019;48(1):16–31.

33. Gall B, Parkhouse W. Changes in physical capacity as a function of age in heavy manual work. *Ergonomics*. 2004;47(6):671–87.

34. Jebens E, Mamen A, Medbø JI, Knudsen O, Veiersted KB. Are elderly construction workers sufficiently fit for heavy manual labour? *Ergonomics*. 2015;58(3):450–62.

35. Schibye B, Hansen AF, Søgaard K, Christensen H. Aerobic power and muscle strength among young and elderly workers with and without physically demanding work tasks. *Appl Ergon*. 2001;32(5):425–31.

36. Walker-Bone K, D'Angelo S, Syddall HE, et al. Heavy manual work throughout the working lifetime and muscle strength among men at retirement age. *Occup Environ Med*. 2016;73(4):284–6.

37. Kuh D, Bassey EJ, Butterworth S, Hardy R, Wadsworth MEJ. Grip Strength, Postural Control, and Functional Leg Power in a Representative Cohort of British Men and Women: Associations With Physical Activity, Health Status, and Socioeconomic Conditions. *Journals Gerontol Ser A Biol Sci Med Sci*. 2005;60(2):224–31.

38. Russo A, Onder G, Cesari M, et al. Lifetime occupation and physical function: a prospective cohort study on persons aged 80 years and older living in a community. *Occup Environ Med*. 2006;63(7):438–42.

39. Hairi FM, Mackenbach JP, Andersen-Ranberg K, Avendano M. Does socio-economic status predict grip strength in older Europeans? Results from the SHARE study in non-institutionalised men and women aged 50+. *J Epidemiol Community Heal*. 2010;64(9):829–37.

40. Holtermann A, Krause N, Beek A Van Der, Straker L. The physical activity paradox: six reasons why occupational physical activity (OPA) does not confer the cardiovascular health benefits that leisure time physical activity. *Br J Sports Med*. 2018;52(3):149–50.

41. Punnett L, Wegman DH. Work-related musculoskeletal disorders: The epidemiologic evidence and the debate. *J Electromyogr Kinesiol*. 2004;14(1):13–23.

42. de Zwart BC, Broersen JP, Frings-Dresen MH, van Dijk FJ. Repeated survey on changes in musculoskeletal complaints relative to age and work demands. *Occup Environ Med*. 1997;54(11):793–9.

43. Tammelin T, Näyhä S, Rintamäki H, Zitting P. Occupational physical activity is related to physical fitness in young workers. *Med Sci Sports Exerc*. 2002;34(1):158–65.

44. Finucane MM, Stevens GA, Cowan MJ, et al. National, regional, and global trends in body-mass index since 1980: Systematic analysis of health examination surveys and epidemiological studies with 960 country-years and 9·1 million participants. *Lancet*. 2011;377(9765):557–67.

45. Baumgartner RN. Body composition in healthy aging. *Ann N Y Acad Sci*. 2000;904:437–48.

46. Stenholm S, Harris T, Rantanen T, Visser M, Kritchevsky SB, Ferrucci L. Sarcopenic obesity-definition, etiology and consequences. *Curr Opin Clin Nutr Metab Care*. 2008;11(6):693–700.

47. Jackson AS, Janssen I, Sui X, Church TS, Blair SN. Longitudinal changes in body composition associated with healthy ageing: men, aged 20-96 years. *Br J Nutr*. 2012;107(1):1085–91.

48. Janssen I, Heymsfield SB, Wang ZM, Ross R. Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol*. 2000;89(1):81–8.

49. Mitchell WK, Williams J, Atherton P, Larvin M, Lund J, Narici M. Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. *Front Physiol*. 2012;3:260.

50. Lexell J, Taylor CC, Sjöström M. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *J Neurol Sci*. 1988;84(2–3):275–94.

51. Janssen I, Heymsfield SB, Ross R. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc*. 2002;50(5):889–96.

52. Cesari M, Kritchevsky SB, Baumgartner R, et al. Sarcopenia, obesity, and inflammation—results from the Trial of Angiotensin Converting Enzyme Inhibition and Novel Cardiovascular Risk Factors study. *Am J Clin Nutr*. 2005;82(2):428–34.

53. Fontana L, Eagon JC, Trujillo ME, Scherer PE, Klein S. Visceral Fat Adipokine Secretion Is Associated With Systemic Inflammation in Obese Humans. *Diabetes*. 2007;56(4):1010–3.

54. Chen H, Guo X. Obesity and Functional Disability in Elderly Americans. *J Am Geriatr Soc*. 2008;56(4):689–94.

55. Brady A, Straight CR, Evans EM. Body Composition, Muscle Capacity, and Physical Function in Older Adults: An Integrated Conceptual Model. *J Aging Phys Act*. 2013;22(3):441–52.

56. Tonnon SC, Robroek SRJ, van der Beek AJ, et al. Physical workload and obesity have a synergistic effect on work ability among construction workers. *Int Arch Occup Environ Health*. 2019;92(6):855–64.

57. Saupe K, Sothmann M, Jasenof D. Aging and the fitness of fire fighters: The complex issues involved in abolishing mandatory retirement ages. *Am J Public Health*. 1991;81(9):1192–4.

58. Bann D, Cooper R, Wills AK, Adams J, Kuh D. Socioeconomic position across life and body composition in early old age: Findings from a british birth cohort study. *J Epidemiol Community Health*. 2014;68(6):516–23.

59. Cote M, Kenny A, Dussetschleger J, Farr D, Chaurasia A, Cherniack M. Reference values for physical performance measures in the aging working population. *Hum Factors*. 2014;56(1):228–42.

60. Norheim KL, Samani A, Bønløkke JH, Omland Ø, Madeleine P. Physical-work ability and chronic musculoskeletal complaints are related to leisure-time physical activity: Cross-sectional study among manual workers aged 50–70 years: *Scand J Public Health*. 2019;47(3):375–82.

61. Strickland JR, Wagan S, Dale AM, Evanoff BA. Prevalence and Perception of Risky Health Behaviors among Construction Workers. *J Occup Environ Med*. 2017;59(7):673–8.

62. Quintiliani L, Poulsen S, Sorensen G. Healthy eating strategies in the workplace. *Int J Work Heal Manag*. 2010;3(3):182–96.

63. Bassett DR, Howley ET. Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Med Sci Sports Exerc*. 2000;32(1):70–84.

64. Roman MA, Rossiter HB, Casaburi R. Exercise, ageing and the lung. *Eur Respir J*. 2016;48(5):1471–86.

65. Pimentel AE, Gentile CL, Tanaka H, Seals DR, Gates PE. Greater rate of decline in maximal aerobic capacity with age in endurance-trained than in sedentary men. *J Appl Physiol*. 2003;94(6):2406–13.

66. Hawkins S, Wiswell R. Rate and mechanism of maximal oxygen consumption decline with aging: implications for exercise training. *Sports Med*. 2003;33(12):877–88.

67. Mikkelsen UR, Couppé C, Karlsen A, et al. Life-long endurance exercise in humans: Circulating levels of inflammatory markers and leg muscle size. *Mech Ageing Dev*. 2013;134(11–12):531–40.

68. Heath GW, Hagberg JM, Ehsani AA, Holloszy JO. A physiological

comparison of young and older endurance athletes. *J Appl Physiol Respir Environ Exerc Physiol*. 1981;51(3):634–40.

69. Tanaka H, Seals DR. Endurance exercise performance in Masters athletes: age-associated changes and underlying physiological mechanisms. *J Physiol*. 2008;586(1):55–63.

70. Proctor DN, Joyner MJ. Skeletal muscle mass and the reduction of V̇O2(max) in trained older subjects. *J Appl Physiol*. 1997;82(5):1411–5.

71. Fleg JL. Alterations in cardiovascular structure and function with advancing age. *Am J Cardiol*. 1986;57(5):C33–44.

72. Harber MP, Kaminsky LA, Arena R, et al. Impact of Cardiorespiratory Fitness on All-Cause and Disease-Specific Mortality: Advances Since 2009. *Prog Cardiovasc Dis*. 2017;60(1):11–20.

73. Savinainen M, Nygård C-HH, Ilmarinen J. A 16-year follow-up study of physical capacity in relation to perceived workload among ageing employees. *Ergonomics*. 2004;47(10):1087–102.

74. Korshøj M, Krustrup P, Jespersen T, Søgaard K, Skotte JH, Holtermann A. A 24-h assessment of physical activity and cardio-respiratory fitness among female hospital cleaners: A pilot study. *Ergonomics*. 2013;56(6):935–43.

75. Holtermann A, Hansen J V., Burr H, Søgaard K, Sjøgaard G. The health paradox of occupational and leisure-time physical activity. *Br J Sports Med*. 2012;46(4):291–5.

76. Coenen P, Huysmans MA, Holtermann A, et al. Do highly physically active workers die early? A systematic review with meta-analysis of data from 193 696 participants. *Br J Sports Med*. 2018;52(20):1320–6.

77. Ilmarinen J, Rutenfranz J. Occupationally induced stress, strain and peak loads as related to age. *Scand J Work Environ Heal*. 1980;6(4):274–82.

78. Ilmarinen J, Louhevaara V, Korhonen O, Nygård C-H, Hakola T, Suvanto S. Changes in maximal cardiorespiratory capacity among aging municipal employees. *Scand J Work Environ Health*. 1991;17(suppl 1):99–109.

79. Edvardsen E, Hansen BH, Holme IM, Dyrstad SM, Anderssen SA. Reference values for cardiorespiratory response and fitness on the treadmill in a 20- to 85-year-old population. *Chest*. 2013;144(1):241–8.

80. Nelson ME, Rejeski WJ, Blair SN, et al. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. *Med Sci Sports Exerc*. 2007;39(8):1435–45.

81. Dockery DW, Spiro A, Speizer F. Distribution of forced expiratory volume in one second and forced vital capacity in healthy, white, adult never-smokers in six US cities. *Am Rev Respir Dis*. 2085;131(4):511–20.

82. van Oostrom SH, Engelfriet PM, Monique Verschuren WM, et al. Aging-related trajectories of lung function in the general population—The Doetinchem Cohort Study. *PLoS One*. 2018;13(5):1–16.

83. Omland Ø, Würtz ET, Aasen TB, et al. Occupational chronic obstructive pulmonary disease: a systematic literature review. *Scand J Work Environ Health*. 2014;40(1):19–35.

84. Miller MR. Structural and physiological age-associated changes in aging lungs. *Semin Respir Crit Care Med*. 2010;31(5):521–7.

85. Mills DE, Johnson MA, Barnett YA, Smith WHT, Sharpe GR. The effects of inspiratory muscle training in older adults. *Med Sci Sports Exerc*. 2015;47(4):691–7.

86. Bergdahl IA, Toré K, Eriksson K, et al. Increased mortality in COPD among construction workers exposed to inorganic dust. *Eur Respir J*. 2004;23(3):402–6.

87. Dement JM, Welch LS, Ringen K, Cranford K, Quinn P. Longitudinal decline in lung function among older construction workers. *Occup Environ Med*. 2017;74(10):701–8.

88. Lae Chin D, Hong O, Gillen M, Bates MN, Okechukwu CA. Cigarette Smoking in Building Trades Workers: The Impact of Work Environment. *Am J Ind Med*. 2012;55(5):429–39.

89. Liao SY, Lin X, Christiani DC. Occupational exposures and longitudinal lung function decline. *Am J Ind Med*. 2015;58(1):14–20.

90. Einkauf D, Gohdes M, Jensen G. Changes in spinal mobility with increasing age in women. *Phys Ther*. 1987;67(3):370–5.

91. Fukuchi RK, Stefanyshyn DJ, Stirling L, Duarte M, Ferber R. Flexibility, muscle strength and running biomechanical adaptations in older runners. *Clin*

Biomech. 2014;29(3):304–10.

92. Pan F, Arshad R, Zander T, Reitmaier S, Schroll A, Schmidt H. The effect of age and sex on the cervical range of motion – A systematic review and meta-analysis. *J Biomech*. 2018;75:13–27.

93. Tveter AT, Dagfinrud H, Moseng T, Holm I. Health-related physical fitness measures: Reference values and reference equations for use in clinical practice. *Arch Phys Med Rehabil*. 2014;95(7):1366–73.

94. McHugh MP, Cosgrave CH. To stretch or not to stretch: The role of stretching in injury prevention and performance. *Scand J Med Sci Sport*. 2010;20(2):169–81.

95. Alonso J, McHugh MP, Mullaney MJ, Tyler TF. Effect of hamstring flexibility on isometric knee flexion angle-torque relationship. *Scand J Med Sci Sports*. 2008;19(2):252–6.

96. Woods K, Bishop P, Jones E. Warm-up and stretching in the prevention of muscular injury. *Sport Med*. 2007;37(12):1089–99.

97. Amako M, Oda T, Masuoka K, Yokoi H, Campisi P. Effect of Static Stretching on Prevention of Injuries for Military Recruits. *Mil Med*. 2003;168(6):442–6.

98. Stathokostas L, Little RMD, Vandervoort AA, Paterson DH. Flexibility training and functional ability in older adults: A systematic review. *J Aging Res*. 2012;2012 doi:10.1155/2012/306818.

99. Ruzic L, Heimer S, Misigoj-Durakovic M, Matkovic BR. Increased occupational physical activity does not improve physical fitness. *Occup Environ Med*. 2003;60(12):983–5.

100. Harris EC, Coggon D. HIP osteoarthritis and work. *Best Pract Res Clin Rheumatol*. 2015;29(3):462–82.

101. Clemes SA, Haslam CO, Haslam RA. What constitutes effective manual handling training? A systematic review. *Occup Med*. 2009;60(2):101–7.

102. Sadler SG, Spink MJ, Ho A, De Jonge XJ, Chuter VH. Restriction in lateral bending range of motion, lumbar lordosis, and hamstring flexibility predicts the development of low back pain: A systematic review of prospective cohort studies. *BMC Musculoskelet Disord*. 2017;18(1):179.

103. Balaguier R, Madeleine P, Rose-Dulcina K, Vuillerme N. Effects of a Worksite Supervised Adapted Physical Activity Program on Trunk Muscle Endurance, Flexibility, and Pain Sensitivity Among Vineyard Workers. *J Agromedicine*. 2017;22(3):200–14.

104. Seidler RD, Bernard JA, Burutolu TB, et al. Motor control and aging: Links to age-related brain structural, functional, and biochemical effects. *Neurosci Biobehav Rev*. 2010;34(5):721–33.

105. Bohannon RW, Bubela DJ, Magasi SR, Wang YC, Gershon RC. Sit-to-stand test: Performance and determinants across the age-span. *Isokinet Exerc Sci*. 2010;18(4):235–40.

106. Marmon AR, Pascoe MA, Schwartz RS, Enoka RM. Associations among strength, steadiness, and hand function across the adult life span. *Med Sci Sports Exerc*. 2011;43(4):560–7.

107. Christou EA. Aging and Variability of Voluntary Contractions. *Exerc Sport Sci Rev*. 2011;39(2):77–84.

108. Oomen NMCW, van Dieën JH. Effects of age on force steadiness: A literature review and meta-analysis. *Ageing Res Rev*. 2017;35:312–21.

109. Prieto TE, Myklebust JB, Hoffmann RG, Lovett EG, Myklebust BM. Measures of postural steadiness: Differences between healthy young and elderly adults. *IEEE Trans Biomed Eng*. 1996;43(9):956–66.

110. Roman-Liu D. Age-related changes in the range and velocity of postural sway. *Arch Gerontol Geriatr*. 2018;77:68–80.

111. Leveille SG, Jones RN, Kiely DK, et al. Chronic Musculoskeletal Pain and the Occurrence of Falls in an Older Population. *JAMA*. 2009;302(20):2214.

112. Picorelli AMA, Hatton AL, Gane EM, Smith MD. Balance performance in older adults with hip osteoarthritis: A systematic review. *Gait Posture*. 2018;65(June):89–99.

113. Hirata RP, Ervilha UF, Arendt-Nielsen L, Graven-Nielsen T. Experimental Muscle Pain Challenges the Postural Stability During Quiet Stance and Unexpected Posture Perturbation. *J Pain*. 2011;12(8):911–9.

114. Der G, Deary IJ. Age and sex differences in reaction time in adulthood: Results from the United Kingdom Health and Lifestyle Survey. *Psychol Aging*. 2006;21(1):62–73.

115. Woods DL, Wyma JM, Yund EW, Herron TJ, Reed B. Age-related slowing of response selection and production in a visual choice reaction time task. *Front Hum Neurosci*. 2015;9:193.

116. Salvia E, Petit C, Champely S, Chomette R, Di Rienzo F, Collet C. Effects of Age and Task Load on Drivers' Response Accuracy and Reaction Time When Responding to Traffic Lights. *Front Aging Neurosci*. 2016;8:169.

117. Lord SR, Murray SM, Chapman K, et al. Sit-to-stand performance depends on sensation, speed, balance, and psychological status in addition to strength in older people Incidence and epidemiology of anal cancer in the multicenter AIDS cohort study. *J Gerontol A Biol Sci Med Sci*. 714;57(8):M543.

118. Buatois S, Miljkovic D, Manckoundia P, et al. Five times sit to stand test is a predictor of recurrent falls in healthy community-living subjects aged 65 and older. *J Am Geriatr Soc*. 2008;56(8):1575–7.

119. Guralnik JM, Ferrucci L, Simonsick EM, Salive ME, Wallace RB. Lower-extremity function in persons over the age of 70 years as a predictor of subsequent disability. *N Engl J Med*. 1995;332(9):556–61.

120. Srinivasan D, Mathiassen SE. Motor variability in occupational health and performance. *Clin Biomech*. 2012;27(10):979–93.

121. Madeleine P. On functional motor adaptations: from the quantification of motor strategies to the prevention of musculoskeletal disorders in the neck-shoulder region. *Acta Physiol*. 2010;199:1–46.

122. Madeleine P, Mathiassen SE, Arendt-Nielsen L. Changes in the degree of motor variability associated with experimental and chronic neck-shoulder pain during a standardised repetitive arm movement. *Exp Brain Res*. 2008;185(4):689–98.

123. Madeleine P, Voigt M, Mathiassen SE. The size of cycle-to-cycle variability in biomechanical exposure among butchers performing a standardised cutting task. *Ergonomics*. 2008;51(7):1078–95.

124. Møller A, Reventlow S, Hansen ÅM, et al. Does physical exposure throughout working life influence chair-rise performance in midlife? A retrospective cohort study of associations between work and physical function in Denmark. *BMJ Open*. 2015;5(11):e009873.

125. Leino-Arjas P, Solovieva S, Riihimäki H, Kirjonen J, Telama R. Leisure time physical activity and strenuousness of work as predictors of physical

functioning: a 28 year follow up of a cohort of industrial employees. *Occup Environ Med*. 2004;61(12):1032–8.

126. Cassou B, Derriennic F, Iwatsubo Y, Amphoux M, Lorrain C, Amphoux FM. Physical disability after retirement and occupa-tional risk factors during working life: a cross sectional epidemiological study in the Paris area. *J Epidemiol Community Health*. 1992;46(5):506–51.

127. von Bonsdorff ME, Kokko K, Seitsamo J, et al. Work strain in midlife and 28-year work ability trajectories. *Scand J Work Environ Heal*. 2011;37(6):455–63.

128. Ilmarinen J, Tuomi K, Klockars M. Changes in the work ability of active employees over an 11-year period. *Scand J Work Environ Health*. 1997;49–57.

129. Punakallio A, Lusa S, Ala-Mursula L, et al. Personal meaning of work and perceived work ability among middle-aged workers with physically strenuous work: a Northern Finland Birth Cohort 1966 Study. *Int Arch Occup Environ Health*. 2019;92(3):371–81.

130. Kenny GP, Groeller H, McGinn R, Flouris AD. Age, human performance, and physical employment standards. *Appl Physiol Nutr Metab*. 2016;41(6 (Suppl. 2)):S92–107.

131. Savinainen M, Nygård CH, Korhonen O, Ilmarinen J. Changes in Physical Capacity Among Middle-Aged Municipal Employees Over 16 Years. *Exp Aging Res*. 2004;30(1):1–22.

132. Kittel F, Leynen F, Stam M, et al. Job conditions and fibrinogen in 14226 Belgian workers. The Belstress study. *Eur Heart J*. 2002;23:1841–8.

133. Tsutsumi A, Theorell T, Hallqvist J, Reuterwall C, De Faire U. Association between job characteristics and plasma fibrinogen in a normal working population: a cross sectional analysis in referents of the SHEEP study. *J Epidemiol Community Heal*. 1999;53:348–54.

134. Courtney TK, Matz S, Webster BS. Disabling occupational injury in the US construction industry, 1996. *J Occup Environ Med*. 2002;44(12):1161–8.

135. Tuomi K, Ilmarinen J, Eskelinen L, Järvinen E, Toikkanen J, Klockars M. Prevalence and incidence rates of diseases and work ability in different work categories of municipal occupations. *Scand J Work Environ Health*. 1991;17 Suppl 1:67–74.

136. Karpansalo M, Manninen P, Lakka T, Kauhanen J, Rauramaa R, Salonen J. Physical workload and risk of early retirement: prospective population-based study among middle-aged men. *J Occup Environ Med*. 2002;44:930–9.

137. Krause N, Brand RJ, Kaplan GA, et al. Occupational physical activity, energy expenditure and 11-year progression of carotid atherosclerosis. *Scand J Work Environ Heal*. 2007;33(6):405–24.

138. Wang A, Arah OA, Kauhanen J. Effects of leisure-time and occupational physical activities on 20-year incidence of acute myocardial infarction: mediation and interaction Publication Date. *Scand J Work Environ Health*. 2016;423–34.

139. Kuorinka I, Jonsson B, Kilbom A, et al. Standardised Nordic questionnaires for the analysis of musculoskeletal symptoms. *Appl Ergon*. 1987;18(3):233–7.

140. Korshøj M, Ravn MH, Holtermann A, Hansen ÅM, Krustrup P. Aerobic exercise reduces biomarkers related to cardiovascular risk among cleaners: effects of a worksite intervention RCT. *Int Arch Occup Environ Health*. 2016;89(2):239–49.

141. Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14:377–81.

142. Maffiuletti NA, Aagaard P, Blazevich AJ, Folland J, Tillin N, Duchateau J. Rate of force development: physiological and methodological considerations. *Eur J Appl Physiol*. 2016;116(6):1091–116.

143. Rantanen T, Volpato S, Ferrucci L, Heikkinen E, Fried LP, Guralnik JM. Handgrip strength and cause-specific and total mortality in older disabled women: Exploring the mechanism. *J Am Geriatr Soc*. 2003;51(5):636–41.

144. Wang CY, Chen LY. Grip strength in older adults: Test-retest reliability and cutoff for subjective weakness of using the hands in heavy tasks. *Arch Phys Med Rehabil*. 2010;91(11):1747–51.

145. Savva C, Mougiaris P, Xadjimichael C, Karagiannis C, Efstathiou M. Test-Retest Reliability of Handgrip Strength as an Outcome Measure in Patients With Symptoms of Shoulder Impingement Syndrome. *J Manipulative Physiol Ther*. 2018;41(3):252–7.

146. Kyle UG, Genton L, Lukaski HC, et al. Comparison of fat-free mass and body fat in Swiss and American adults. *Nutrition*. 2005;21(2):161–9.

147. Aagaard Lindboe M, Mølbak Christiansen N, Raabye S, Malling Andersen S. *Pålideligheden af multi frekvens bioelektrisk impedans analyse, Inbody 370*. 2017.

148. Ling CHY, de Craen AJM, Slagboom PE, et al. Accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body and segmental body composition in middle-aged adult population. *Clin Nutr*. 2011;30(5):610–5.

149. Anderson LJ, Erceg DN, Schroeder ET. Utility of multifrequency bioelectrical impedance compared with dual-energy x-ray absorptiometry for assessment of total and regional body composition varies between men and women. *Nutr Res*. 2012;32(7):479–85.

150. Karelis AD, Chamberland G, Aubertin-Leheudre M, Duval C, Group E mobility in A and P (EMAP). Validation of a portable bioelectrical impedance analyzer for the assessment of body composition. *Appl Physiol Nutr Metab*. 2013;38(1):27–32.

151. Astrand PO, Ryhming I. A nomogram for calculation of aerobic capacity (physical fitness) from pulse rate during sub-maximal work. *J Appl Physiol*. 1954;7(2):218–21.

152. Shephard RJ. Computer programs for solution of the Astrand nomogram and the calculation of body surface area. *J Sports Med Phys Fitness*. 1970;10(4):206–10.

153. Gram B, Holtermann A, Søgaard K, Sjøgaard G. Effect of individualized worksite exercise training on aerobic capacity and muscle strength among construction workers--a randomized controlled intervention study. *Scand J Work Environ Health*. 2012;38(5):467–75.

154. Jørgensen MB, Gupta N, Korshøj M, et al. The DPhacto cohort: An overview of technically measured physical activity at work and leisure in blue-collar sectors for practitioners and researchers. *Appl Ergon*. 2019;77:29–39.

155. Westerståhl M, Jansson E, Barnekow-Bergkvist M, Aasa U. Longitudinal changes in physical capacity from adolescence to middle age in men and women. *Sci Rep*. 2018;8(1):14767.

156. Macsween A. The reliability and validity of the Astrand nomogram and linear extrapolation for deriving VO2max from submaximal exercise data. *J Sports Med Phys Fitness*. 2001;41(3):312–7.

157. Huggett D, Connelly D, Overend T. Maximal aerobic capacity testing of older adults: a critical review. *Journals Gerontol Ser A Biol Sci Med Sci*. 2005;60(1):57–66.

158. Miller MR, Hankinson J, Brusasco V, et al. Standardisation of spirometry. *Eur Respir J*. 2005;26(2):319–38.

159. Perret C, Poiraudeau S, Fermanian J, Colau MML, Benhamou MAM, Revel M. Validity, reliability, and responsiveness of the fingertip-to-floor test. *Arch Phys Med Rehabil*. 2001;82(11):1566–70.

160. Ekedahl H, Jönsson B, Frobell RB. Fingertip-to-floor test and straight leg raising test: Validity, responsiveness, and predictive value in patients with acute/subacute low back pain. *Arch Phys Med Rehabil*. 2012;93(12):2210–5.

161. Guralnik JM, Simonsick EM, Ferrucci L, et al. A short physical performance battery assessing lower extremity function: association with self-reported disability and prediction of mortality and nursing home admission. *J Gerontol*. 1994;49(2):M85-94.

162. Fujimoto M, Chou L-S. Dynamic balance control during sit-to-stand movement: An examination with the center of mass acceleration. *J Biomech*. 2012;45(3):543–8.

163. Bruijn S, Meijer O, Beek P, van Dieën J. Assessing the stability of human locomotion: a review of current measures. *J R Soc Interface*. 2013;10(83):20120999.

164. Lockhart TE, Liu J. Differentiating fall-prone and healthy adults using local dynamic stability. *Ergonomics*. 2008;51(12):1860–72.

165. Pincus SM, Goldberger AL. Physiological time-series analysis: what does regularity quantify? *Am J Physiol*. 1994;266(4 Pt 2):H1643-1656.

166. Vaillancourt DE, Newell KM. Changing complexity in human behavior and physiology through aging and disease. *Neurobiol Aging*. 2002;23(1):1–11.

167. Ayoub MM, Miller M. Industrial Workplace Design. *Adv Hum Factors/Ergonomics*. 1991;15:67–92.

168. Wang W-E, Roy A, Misra G, et al. Motor-Evoked Pain Increases Force Variability in Chronic Jaw Pain. *J Pain*. 2018;19(6):636–48.

169. Kennedy DM, Christou EA. Greater amount of visual information exacerbates

force control in older adults during constant isometric contractions. *Exp Brain Res*. 2011;213(4):351–61.

170. Vaillancourt DE, Newell KM. Aging and the time and frequency structure of force output variability. *J Appl Physiol*. 2003;94(3):903–12.

171. Svendsen JH, Madeleine P. Amount and structure of force variability during short, ramp and sustained contractions in males and females. *Hum Mov Sci*. 2010;29(1):35–47.

172. Nygaard H, Falch GS, Whist JE, et al. Acute effects of post-absorptive and. *Eur J Appl Physiol*. 2017;117(4):787–94.

173. Tholstrup T, Teng K-T, Raff M. Dietary Cocoa Butter or Refined Olive Oil Does Not Alter Postprandial hsCRP and IL-6 Concentrations in Healthy Women. *Lipids*. 2011;46(4):365–70.

174. Poppitt SD, Keogh GF, Lithander FE, et al. Postprandial response of adiponectin, interleukin-6, tumor necrosis factor-α, and C-reactive protein to a high-fat dietary load. *Nutrition*. 2008;24(4):322–9.

175. Haack M, Kraus T, Schuld A, Dalal M, Koethe D, Pollmächer T. Diurnal variations of interleukin-6 plasma levels are confounded by blood drawing procedures. *Psychoneuroendocrinology*. 2002;27(8):921–31.

176. Madeleine P, Vangsgaard S, Hviid Andersen J, Ge H-Y, Arendt-Nielsen L. Computer work and self-reported variables on anthropometrics, computer usage, work ability, productivity, pain, and physical activity. *BMC Musculoskelet Disord*. 2013;14:226.

177. Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L. Sensory manifestations in experimental and work-related chronic neck-shoulder pain. *Eur J pain*. 1998;2(3):251–60.

178. Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L. Shoulder muscle co-ordination during chronic and acute experimental neck-shoulder pain. An occupational pain study. *Eur J Appl Physiol*. 1999;79(2):127–40.

179. Ilmarinen J. The Work Ability Index (WAI). *Occup Med*. 2007;57(2):160–160.

180. Maxwell SE. Sample size and multiple regression analysis. *Psychol Methods*. 2000;5(4):434–58.

181. Enoka RM, Duchateau J. Translating Fatigue to Human Performance. *Med Sci Sport Exerc*. 2016;48(11):2228–38.

182. Cnaan A, Laird NM, Slasor P. Using the general linear mixed model to analyse unbalanced repeated measures and longitudinal data. *Stat Med*. 1997;16(20):2349–80.

183. Cole TJ. Sympercents: Symmetric percentage differences on the 100 log(e) scale simplify the presentation of log transformed data. *Stat Med*. 2000;19(22):3109–25.

184. Cole TJ, Altman DG. Statistics Notes: Percentage differences, symmetry, and natural logarithms. *BMJ*. 2017;(358):j3683.

185. Suetta C, Haddock B, Alcazar J, et al. The Copenhagen Sarcopenia Study: lean mass, strength, power, and physical function in a Danish cohort aged 20–93 years. *J Cachexia Sarcopenia Muscle*. 2019;jcsm.12477.

186. Centers for Disease Control and Prevention (CDC). National Center for Health Statistics (NCHS). National Health and Nutrition Examination Survey Questionnaire (or Examination Protocol, or Laboratory Protocol). Hyattsville, MD: U.S. Department of Health an Available from: http://www.cdc.gov/nchs/nhanes.htm.

187. Norheim KL, Samani A, Bønløkke JH, Omland Ø, Madeleine P. Objective predictors of physical work ability in aged manual workers. *PREMUS 2019 10th International Scientific Conference on the Prevention of Work-Related Musculoskeletal Disorders: Book of Abstracts*. 2019. p. 210.

188. Clays E, Lidegaard M, De Bacquer D, et al. The combined relationship of occupational and leisure-time physical activity with all-cause mortality among men, accounting for physical fitness. *Am J Epidemiol*. 2014;179(5):559–66.

189. Møller A, Reventlow S, Hansen ÅM, et al. Does a history of physical exposures at work affect hand-grip strength in midlife? A retrospective cohort study in Denmark. *Scand J Work Environ Health*. 2013;39(6):599–608.

190. Nygård CH, Luopajärvi T, Ilmarinen J. Musculoskeletal capacity and its changes among aging municipal employees in different work categories. *Scand J Work Environ Health*. 1991;17 Suppl 1:110–7.

191. Gale C, Martyn C, Cooper C, Sayer A. Grip strength, body composition, and mortality. *Int J Epidemiol*. 2006;26(1):228–35.

192. Stenholm S, Tiainen K, Rantanen T, et al. Long-Term Determinants of Muscle Strength Decline: Prospective Evidence from the 22-Year Mini-Finland Follow-Up Survey. *J Am Geriatr Soc*. 2012;60(1):77–85.

193. Torgén M, Punnett L, Alfredsson L, Kilbom Å. Physical capacity in relation to present and past physical load at work: A study of 484 men and women aged 41 to 58 years. *Am J Ind Med*. 1999;36(3):388–400.

194. Hunter SK, Critchlow A, Enoka RM. Influence of aging on sex differences in muscle fatigability. *J Appl Physiol*. 2004;97(5):1723–32.

195. Hunter SK, Critchlow A, Enoka RM. Muscle endurance is greater for old men compared with strength-matched young men. *J Appl Physiol*. 2005;99(3):890–7.

196. Aagaard P, Suetta C, Caserotti P, Magnusson SP, Kjaer M. Role of the nervous system in sarcopenia and muscle atrophy with aging: strength training as a countermeasure. *Scand J Med Sci Sports*. 2010;20(1):49–64.

197. Hakkinen K. Neuromuscular fatigue and recovery in women at different ages during heavy resistance loading. *Electromyogr Clin Neurophysiol*. 1995;35(7):403–13.

198. Morton RW, Colenso-Semple L, Phillips SM. Training for strength and hypertrophy: an evidence-based approach. *Curr Opin Physiol*. 2019;10:90–5.

199. Bickel CS, Cross JM, Bamman MM. Exercise dosing to retain resistance training adaptations in young and older adults. *Med Sci Sports Exerc*. 2011;43(7):1177–87.

200. Grier T, Canham-Chervak M, Sharp M, Jones BH. Does body mass index misclassify physically active young men. *Prev Med Reports*. 2015;2:483–7.

201. Westerterp KR. Exercise, energy balance and body composition. *Eur J Clin Nutr*. 2018;72(9):1246–50.

202. Schoenfeld BJ. The mechanisms of muscle hypertrophy and their application to resistance training. *J Strength Cond Res*. 2010;24(10):2857–72.

203. Norheim KL, Cullum CK, Andersen JL, Kjaer M, Karlsen A. Inflammation relates to resistance training-induced hypertrophy in elderly patients. *Med Sci Sports Exerc*. 2017;49(6):1079–85.

204. Suetta C, Hvid LG, Justesen L, et al. Effects of aging on human skeletal

muscle after immobilization and retraining. *J Appl Physiol (Bethesda, Md 1985)*. 2009;107(4):1172–80.

205. Karlsen A, Cullum CK, Norheim KL, et al. Neuromuscular Electrical Stimulation Preserves Leg Lean Mass in Geriatric Patients. *Med Sci Sport Exerc*. 2019; doi:10.1249/MSS.0000000000002191.

206. Tchernof A, Després JP. Pathophysiology of human visceral obesity: An update. *Physiol Rev*. 2013;93(1):359–404.

207. Merkus SL, Lunde LK, Koch M, Wærsted M, Knardahl S, Veiersted KB. Physical capacity, occupational physical demands, and relative physical strain of older employees in construction and healthcare. *Int Arch Occup Environ Health*. 2019;92(3):295–307.

208. Hawkins SA, Marcell TJ, Jaque SV, Wiswell RA. A longitudinal assessment of change in VO2max and maximal heart rate in master athletes. *Med Sci Sports Exerc*. 2001;33(10):1744–50.

209. Pollock ML, Gaesser GA, Butcher JD, et al. ACSM Position Stand: The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Healthy Adults. *Med Sci Sport Exerc*. 1998;30(6):975–91.

210. Gibala MJ, Little JP, van Essen M, et al. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. *J Physiol*. 2006;575(Pt 3):901–11.

211. Franklin BA, Swain DP. New insights on the threshold intensity for improving cardiorespiratory fitness. *Prev Cardiol*. 2003;6(3):118–21.

212. Montoye HJ, Gayle R, Higgins M. Smoking habits, alcohol consumption and maximal oxygen uptake. *Med Sci Sports Exerc*. 1980;12(5):316–21.

213. Sorensen G, Barbeau EM, Stoddard AM, et al. Tools for health: The efficacy of a tailored intervention targeted for construction laborers. *Cancer Causes Control*. 2007;18(1):51–9.

214. Mista CA, Christensen SW, Graven-Nielsen T. Modulation of motor variability related to experimental muscle pain during elbow-flexion contractions. *Hum Mov Sci*. 2015;39:222–35.

215. Madeleine P, Lundager B, Voigt M, Arendt-Nielsen L. The effects of neck-shoulder pain development on sensory-motor interactions among female

workers in the poultry and fish industries. A prospective study. *Int Arch Occup Environ Health*. 2003;76(1):39–49.

216. Madeleine P, Nielsen M, Arendt-Nielsen L. Characterization of postural control deficit in whiplash patients by means of linear and nonlinear analyses - A pilot study. *J Electromyogr Kinesiol*. 2011;21(2):291–7.

217. Madeleine P, Prietzel H, Svarrer H, Arendt-Nielsen L. Quantitative posturography in altered sensory conditions: a way to assess balance instability in patients with chronic whiplash injury. *Arch Phys Med Rehabil*. 2004;85(3):432–8.

218. van den Berg TIJ, Elders LAM, de Zwart BCH, Burdorf A. The effects of work-related and individual factors on the Work Ability Index: a systematic review. *Occup Environ Med*. 2009;66(4):211–20.

219. Andersen LL, Jensen PH, Sundstrup E. Barriers and opportunities for prolonging working life across different occupational groups: the SeniorWorkingLife study. *Eur J Public Health*. 2019;0(0):1–6.

220. Brandt M, Madeleine P, Samani A, et al. Effects of a Participatory Ergonomics Intervention With Wearable Technical Measurements of Physical Workload in the Construction Industry: Cluster Randomized Controlled Trial. *J Med Internet Res*. 2018;20(12):e10272.

221. Straker L, Mathiassen SE, Holterman A. The "Goldilocks Principle": Designing physical activity at work to be "just right" for promoting health. *Br J Sports Med*. 2018;818–9.

222. Hubal MJ, Gordish-dressman H, Thompson PD, et al. Muscle Size and Strength Gain after Unilateral Resistance Training. *Med Sci Sport Exerc*. 2005;37(6):964–72.

223. Chodzko-Zajko WJ, Proctor DN, Fiatarone Singh MA, et al. Exercise and Physical Activity for Older Adults. *Med Sci Sports Exerc*. 2009;41(7):1510–30.

224. American College of Sports Medicine. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc*. 2009;41(3):687–708.

225. Sjøgaard G, Christensen JR, Justesen JB, et al. Exercise is more than medicine: The working age population's well-being and productivity. *J Sport Heal Sci*. 2016;5(2):159–65.

APPENDICES

Appendix 1: STUDY I

Appendix 2: STUDY II

Appendix 3: STUDY III

Appendix 4: STUDY IV

Appendix 5: STUDY V

ISSN (online): 2246-1302
ISBN (online): 978-87-7210-613-7

AALBORG UNIVERSITY PRESS